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SUPERTROOP VIA I-PORT: DISTRIBUTED SIMULATION TECHNOLOGY FOR COMBAT DEVELOPMENT AND TRAINING DEVELOPMENT

Paul F. Gorman

August 1990

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August 1990

INSTITUTE FOR DEFENSE ANALYSES
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FOREWORD

This paper, prepared for the Institute for Defense Analyses and its program on Advanced Distributed Simulation Technology, proposes concepts to guide research and development on doctrine, organizations, and materiel for war-fighting (combat development), and techniques and equipment for training for war-fighting (training development).

The technology discussed here is embodied in SIMNET (Large Scale SIMulator NETwork). Developed by the Defense Advanced Research Projects Agency (DARPA), SIMNET has successfully demonstrated that relatively low-cost simulators can provide combat readiness for combat vehicle crews and their units through battalion echelon. Hundreds of full-crew simulators of tanks, infantry fighting vehicles, helicopters, and close support fixed-wing aircraft--each with its own computer--can be interconnected, both locally and over great distances. Computer Image Generators (CIG) present to each member of each crew an appropriate three-dimensional view of a virtual battlefield, and these crews can interact with each other as friend or foe in engagement simulation that provides an effective approximation of close combat. Over the next several years, SIMNET will be fielded by the Army as its Combined Arms Tactical Training System (CATTS).

Preparations are now underway to explore mechanisms and techniques beyond the present capabilities of SIMNET through research and development programs referred to as "Advanced Distributed Simulation Technology." This paper seeks to identify productive and achievable goals for those programs.

The substance of this document has appeared in two earlier papers for the Institute for Defense Analyses, circulated to a limited audience for review and comment, one in early December 1989, and the second in early February 1990.[1]

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1 "ST *via* I-Port," prepared for the Institute for Defense Analyses by Cardinal Point, Inc., Afton, Virginia, 10 December 1989; and "ST *via* I-Port: An Operational Rationale," CPI, Afton, 1 February 1990.

In the first of these, the term "SuperTroop" or "ST" was applied to the various technologies that would comprise a man-leveraging infantry battle dress, one with a powered exoskeleton and advanced body armor. The term "I-Port" was coined to describe an individual interface with Advanced Distributed Simulation Technology, and the proposal was made to use I-Port to prototype key components of SuperTroop. I-Port would launch systematic work with exoskeletons and helmets, and explore the cost effectiveness of SuperTroop, while, in parallel, development of other technologies requisite for the operational system took place. In the latter paper, Operation JUST CAUSE in Panama was analyzed to determine whether ST and I-Port--had they been developed and available--would have made a difference in costs and effectiveness of USCINCSO's forces.

ABSTRACT

This paper proposes research and development aimed at total encapsulation of an individual who fights on foot, predicated upon integrating a powered exoskeleton into his battle dress to augment load-bearing capability, a personal computer networked with those of fellow combatants, and full body protection against ballistic, chemical, thermal, and directed energy threats. Fielded first would be a simulation of the eventual battle dress--termed ST, for SuperTroop--which could give individual combatants a portal into Advanced Distributed Simulation--called I-Port. I-Port would then be used to explore the requirements for the exoskeleton, for the personal processor, for the integrated displays and control mechanisms, and for the protective and homeostatic subsystems. I-Port would also produce parametric data on the man-machine interface essential to proceeding with confidence into hardware design and construction. To test the utility of ST/I-Port, Operation JUST CAUSE in Panama is analyzed, with the conclusion that the availability of ST/I-Port equipment might have lowered operational costs and increased force effectiveness. A development program, with the DARPA in the lead, is described.

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ABBREVIATIONS

ABS	Advanced Battle Simulation
ACME	Aircrew Combat Mission Enhancement
ADST	Advanced Distributed Simulation Technology
AERU	Airborne Exoskeletal Reinforcement Unit
AMC	Army Materiel Command
ASV	Adaptive Suspension Vehicle
C^3I	Command, Control, Communications, and Intelligence
CATTS	Combined Arms Tactical Training System
CBRNT	Chemical, Biological, Radiological, Nuclear, Thermal
CCTT	Close Combat Tactical Trainer
CIG	Computer Image Generator
CINC	Commander-in-Chief (of a U.S. combatant command)
COEMMRE	Center of Excellence for Military Medical Research and Education
CP	Command Post
CPI	Cardinal Point, Incorporated
CSRDF	Crew Station Research and Development Facility
DARPA	Defense Advanced Research Projects Agency
DMA	Defense Mapping Agency
FTS	Flight Telerobotic Services
GPS	Global Positioning System
HIC	High Intensity Conflict
HMOS	Helmet Mounted Oculometer System
IDA	Institute for Defense Analyses
IFS	Integrated Fighting System

IOC	Initial Operational Capability
I-Port	Individual Portal (into Advanced Distributed Simulation)
JCS	Joint Chiefs of Staff
JSSAP	Joint Service Small Arms Program Office
LAN	Local Area Network
LANL	Los Alamos National Laboratory, Department of Energy
LHN	Long Haul Network
LIC	Low Intensity Conflict
MAC	Military Airlift Command
MANPAD	Man-Portable Air Defense (Weapon)
MANPRINT	Manpower Requirement Integration
MAW	Medium Antitank Weapon
MCCLS	Medical Combat Casualty Locater System
MEMS	Micro Electrical-Mechanical Systems
MIC	Medium Intensity Combat
PASGT	Personnel Armor System for Ground Troops
PBZT	Polybenzthiazole
PDU	Protocol Data Unit
SAC	Strategic Air Command
SIMNET	(Large Scale) SIMulator NETwork
SIPE	Soldier Integrated Protective Ensemble
SOFPARS	Special Operations Force Planning and Rehearsal System
SRI	Stanford Research Institute
ST	SuperTroop
ST/LIC	SuperTroop for Low Intensity Conflict
STPMS	SuperTroop Physiological Monitor System
TTO	Tactical Technology Office
VIVED	Virtual Visual Environment Display

SUMMARY

Two trends affecting combatants who fight on foot are apparent over recent decades: (1) advances in firepower, mobility, and communications have brought about increased dispersion, and thereby greater demands upon the individual soldier; and (2) as protective devices are added to reduce vulnerability, infantry battle dress approaches encapsulation. This study proposes research and development of total encapsulation, predicated upon integrating a powered exoskeleton to augment the fighter's load-bearing capability with a powerful personal computer networked with those of fellow combatants, and full body protection against ballistic, chemical, thermal, and directed energy threats.

The developmental approach hinges on fielding first a simulation of the eventual battle dress--termed ST, for SuperTroop--which could function as a portal for individual combatants into Advanced Distributed Simulation--called I-Port. I-Port would then be used to explore the requirements for the exoskeleton, for the personal processor, for the integrated displays and control mechanisms, and for the protective and homeostatic subsystems. I-Port would also produce parametric data on the man-machine interface essential to proceeding with confidence into hardware design and construction.

To test these hypotheses, Operation JUST CAUSE in Panama is analyzed, with the conclusion that the availability of ST/I-Port equipment might have lowered operational costs and increased force effectiveness.

Finally, a development program is described, with the Defense Advanced Research Projects Agency (DARPA) in the lead.

I. WARS AHEAD

With the increase of firepower in land warfare since the middle of the 19th Century, there has been an accompanying trend toward dispersing forces on the battlefield. The impetus towards dispersion came first from the ogival projectile about the time of the American Civil War,[2] and second, from fragmentation mur' 'ns during World Wars I and II.[3] Armies have nonetheless become ever more efficient in controlling land and people. This seeming contradiction is readily explained by improvements in C^3I, mobility, and armor protection within combatant formations.

Figure I-1 summarizes trends in the Army's use of land area in battle, including data for armored or mechanized battalions defending NATO in Central Europe during the 1980s, and projections into the next century based on weapons, intelligence means, mobility, communications, and decisional aids now under development.[4] Fighters on foot are becoming fewer, and they are expected to control ever larger amounts of terrain.

However, the experience of wars of the past century may be an inadequate guide to preparing for wars in the decades ahead. Many American strategists have come to realize

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2 Dupuy, Col. T.N., *Numbers, Predictions, and War*, MacDonald and Jane's, London, 1979, p. 7, in which the author plots lethality (killing capacity per hour) increasing from 400 B.C. to the present by six orders of magnitude, while dispersion (square meters per man in combat) increases by four orders of magnitude. Dupuy notes that the technological change which had the greatest influence on modern ground warfare occurred between 1850 and 1860, when the introduction of conoidal bullets enabled infantry to deliver accurate, lethal fire for hundreds of meters, vice tens.

3 Ellis, John, *The Sharp End*, New York, 1980, pp. 176-177. British medical records trace the transformation from domination of direct-fire weapons to supremacy of indirect fire: in the first two years of World War I, bullets caused more than three out of four wounds, but as the war continued, fragmentation wounds became more common. In World War II, three out of four wounds among British forces were caused by explosive munitions: grenades, mines, mortar and artillery projectiles, and aerial bombs.

4 Cf., Department of the Army, Training Circular 25-1, *Training Land*, 4 August 1978, pp. 4-11. A useful summary of changes in methods and means for waging war over the centuries of recorded history is Kenneth Macksey, *The History of Land Warfare*, New York, 1974. N.B., graphics on the end papers. Macksey held that there were definite limits on trends evident as he wrote, and that, for mid- and high intensity warfare, "somewhere about 1980 a point will be reached when it will no longer be possible for battlefield movement to take place without an opponent being instantly aware of it and without an almost immediate and whole destructive engagement. In essence, the advantage of surprise may be almost impossible to acquire by the methods of the past and the defensive will again become supreme."

that the most dangerous kinds of *possible* wars--intense conflicts involving our most powerful forces and arms, including nuclear weapons--are not the most probable, as Figure I-2 suggests.

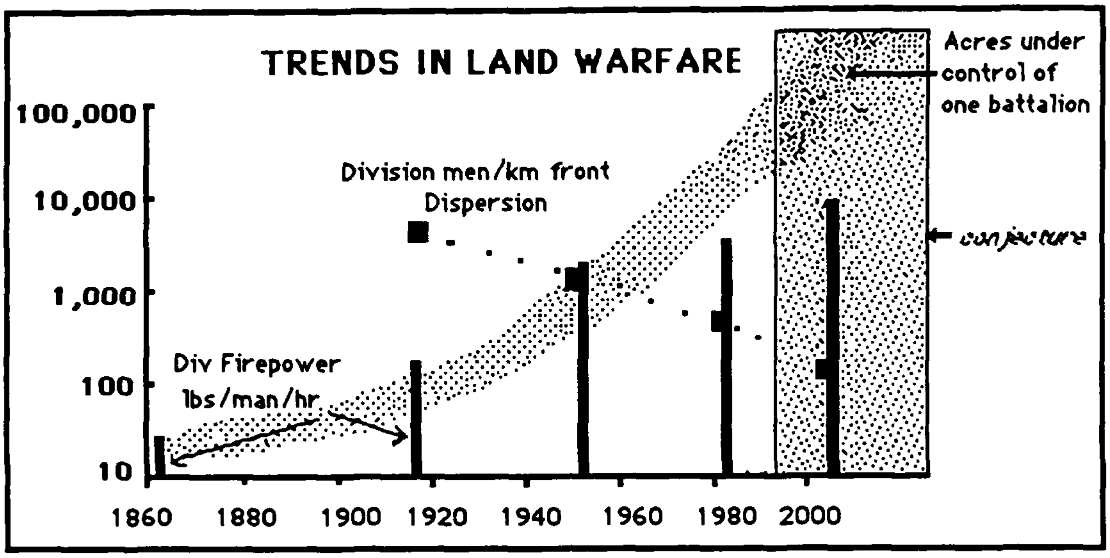

Figure I-1. Trends in Land Warfare

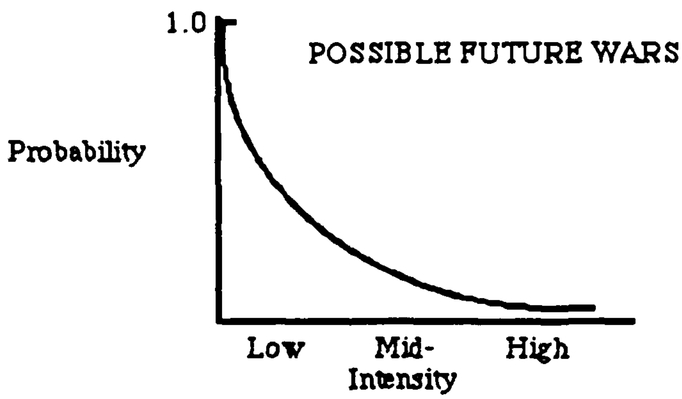

Figure I-2. Possible Intensity of Future Wars

As Soviet hegemony disintegrates, U.S. armed forces have been enjoined, by Congress, *inter alia*, to raise readiness for contingencies likely to develop in the

Third World.[5] (The Joint Chiefs of Staff have undertaken a semantic foray with the term "operational continuum" defined as politico-military states of "peacetime competition," "conflict" and "war.") The JCS seeks to clarify the requirements of theater CINCs in dealing with the contingencies of tomorrow.[6] Uncertain as the time, place and circumstance of those contingencies may be, it is predictable that constraints will almost certainly be placed on the use of U.S. weapons and destructive maneuver, and there is bound to be a high political premium on avoiding U.S. casualties.

The Honorable Paul D. Wolfowitz, Under Secretary of Defense for Policy, recently described the "new strategic thinking" of the Office of the Secretary of Defense, as including the following concepts: [7]

> We also have to concentrate on what one might call the 'stability mission.' In addition to the remaining Soviet challenge, which will be formidable, and various Third World threats, it is clear that we will remain a global power with interests throughout the world. We will remain the ultimate guarantor of order in many parts of the world. We will have to discharge these responsibilities in different ways, however, and probably with less forward basing.
>
> We should make the investments needed to explore promising new military technologies....Moreover, as Third World military challenges become more difficult, we will want to insure that we enjoy decisive advantages over potential opponents. In particular, we will press ahead in those areas that will enable us to use force without exposing more American servicemen and women to risk than is absolutely necessary....

Protecting Americans during combat will be a challenge for strategists, tacticians, and technologists alike. Even in "low intensity" conflict,[8] given the availability of deadly weapons worldwide, combatants must expect to encounter deadly ordnance. Soviet forces, in their campaigns in Afghanistan, strewed the countryside with small anti-personnel mines, with the result that among Afghan war refugees in neighboring Pakistan, there were reported to be 80,000 amputees. Large vehicular-borne explosive devices have become a weapon-of-choice for terrorists, e.g., the U.S. Embassy and the U.S. Marine billets in

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5 In the *Defense Reorganization Act of 1986*, Congress mandated the creation of the U.S. Special Operations Command and the office of the Assistant Secretary of Defense for Special Operations and Low Intensity Conflict, and expressed its sense that the President should form a Low Intensity Conflict Board within the National Security Council.

6 JCS Test Publication 3-0, *Doctrine for Joint Operations*.

7 Remarks Prepared for Delivery at the National Defense University, 17 November 1989, Press Release, ASD (PA) No. 520-89.

8 Defined in JCS Publication 1-02.

Beirut, and the Police Headquarters in Bogotá. The Iran-Iraq War made it clear that even secondary powers can employ chemical weapons and ballistic missiles. The fact is that any future battlefield is likely to be a dangerous place.

Indeed, there is a serious question whether dismounted combatants can survive and function if opposed by such portended weapons as blinding lasers, focused microwave "cookers," broadcast antipersonnel munitions, compound chemical weapons, conventional munitions optimized for anti-personnel effects from blast or fragmentation, and rapid fire guns pointed by thermal imaging sights. Infantrymen have been vulnerable on all 20th century battlefields: soldiers fighting afoot have accounted for the overwhelming majority of battle casualties in any war of the era. During World War II, while infantry divisions of the U.S. Army comprised only 10 percent of its total strength, they accounted for 70 percent of wounded and killed in action.[9] Not surprisingly, infantry have also proven to be especially prone to injury from environmental hazards such as weather and disease, as well as to occupational hazards like noise, vehicular accidents, and misdirected friendly ordnance.

One response to these trends might be to develop and field forces built around a two-man tank, a vehicle with extraordinary sentience, armament, and protection, possibly controlling one or more robotic vehicles. But land vehicles have thus far proven vulnerable to enemy countermeasures, too expensive to buy and own, and problematical for strategic mobility. They would certainly be questionably effective in low intensity conflict: even a very high-technology tank might not be able to rescue American hostages in a hotel in San Salvador or Manila. There will be places on every imaginable battlefield where vehicles simply cannot go--e.g., cities and forests--places where dismounted soldiers will have to be used to gain or maintain control. And foot soldiers who can be conveyed abroad in passenger aircraft are inherently strategically mobile. But could they be rendered less vulnerable?

The Army research and development community has been driven over the decades to reduce weight and increase effectiveness for the individual infantryman, but the total load of the soldier seems nonetheless to have increased. The M-16 rifle system was adopted in part because, pound for pound, the rifle plus ammunition delivered more firepower than the Garand design, but soldiers armed with the M-16 carry more than twice as many rounds. Modern grenades and anti-personnel mines are both more lethal and lighter, but soldiers of

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9 Ellis, op. cit., p. 158.

today carry more of them on their person. Modern synthetic-fiber load-bearing equipment is dramatically improved in lightness, comfort, and convenience over the natural-fiber items it replaces. However, rucksacks have become more commodious, and their contents heavier. The helicopter gives the American infantry unprecedented tactical mobility, yet the very ease, even comfort, of riding into battle sitting on the floor of a HU1H, leaning on one's ruck, has facilitated inordinate individual loads. While it is true that rucksacks can be dropped in the landing zone, that act tethers the unit to the landing zone, and impairs its subsequent mobility.

So, while "light infantry" describes the latest model U.S. Army infantry division--rendered lean for strategic mobility--soldiers lacking organic transportation may carry larger personal loads than infantry counterparts in the armored or mechanized divisions, who have an armored infantry fighting vehicle per squad to do most of their lifting. In the Light Infantry Division, the "light fighter" weighs in, man for man, at substantially more than the soldier who fights on foot in "heavy" divisions.

The axiom of war "Make Virtue of Necessity" ought to be brought to bear, and a means found to support the added load that will inevitably find its way onto the legs and back of the infantryman. For a number of years, technologists have contemplated man-amplifying devices through robotics, prostheses, or powered exoskeletons. With enhanced lifting ability, the soldier could be up-armored, shielded from the full range of modern weaponry, provided with micro-climatic controls, and endowed with extraordinary ability to hear, see, move, shoot and communicate. Such enabling technologies are labeled here SuperTroop, or ST. There seems to be an emerging consensus among scientists and engineers that ST can be developed within a decade or two, and a few believe that ST could be realized within 5 years by a serious, broadly conceived, and well-managed research and development program.

SuperTroop must be an integral system; it is the quintessential "man-machine interface." These two facts lead to the proposition that the developmental undertaking ought to begin with construction of a simulator, consisting of a head-mounted audio-visual input-output device, coupled with an exoskeleton for control of physiological interactions. This simulator would allow the soldier wearing it to participate in SIMNET-like virtual battles, pitted against or cooperating with vehicles and other individuals. Its purpose, aside from its eventual training function, would be to explore systematically the mechanical and behavioral relationships between the wearer, the exoskeleton, and the headgear.

The mechanism is referred to below as I-Port, for *Individual Portal into Advanced Distributed Simulation.*

II. PIECEMEAL PROTECTION

To date, the United States has responded to modern threats to its foot soldiers, both in the Army and the Marine Corps, with uncoordinated upgrading of individual protective equipment. Just within the past decade:

- Ear protectors have become required wear.
- The Kevlar unitary helmet has replaced WWII's steel shell/liner.
- Face camouflage ointments and helmet shape modifiers are worn.
- Night vision goggles (light intensifiers) are routinely used.
- Chemical defenses (gas masks and clothing) have been upgraded.
- Goggles for both ballistic and laser protection have been procured.

Each protective measure was intended to be compatible with prescription eye glasses, binoculars, and weapons sights of various configurations and technologies, ranging from simple optics through light intensification to thermal imagery, and to be amenable as well to use with radios, paper maps, compasses, and digital input devices. But, as may be expected, the complicated array of new protective devices has proven onerous both logistically and tactically, in that wearing some or all of them may negate the very reason for having an infantryman in the first place: the government's ultimate purpose is to use his senses and his intelligence to exert discriminating control over territory and its occupants. Chemical defensive gear is especially dysfunctional: it is intolerably uncomfortable, and it isolates the soldier from his comrades and the environment, and thus induces panic.

To lend coherence to what soldiers wear into battle, the U.S. Army has undertaken, through Natick Laboratory of the Army Materiel Command, a development called Soldier Integrated Protective Ensemble (SIPE). SIPE will seek to rationalize the various cranial and respiratory protections, and other accoutrements.

SIPE includes a search for cooling systems for a costume for operating in the presence of chemical agents, or biological or radiological threats. Recently AMC issued the following statement on this developmental thrust:[10]

> The Army is looking to develop a Soldier Integrated Protective Ensemble (SIPE) as a 'head to toe' state of the art fighting system that would improve the survivability of soldiers in a battlefield environment.
>
> The SIPE demonstration would culminate with the field use of the system in the third quarter of FY92, prior to full-scale development. SIPE consists of three major subsystems: Headgear, which would provide complete head, face, neck and eye ballistic protection, soldier-to-soldier short and long range communication, aural protection, vision enhancement/remote weapon sight helmet-mounted display and laser eye protection; Microclimatic Conditioning, which is a power source that currently does not exist, but a generator/alternator design is being sought driven by a Stirling cycle engine; and an integrated modular Advanced Clothing System that will comprise handwear, footwear, load bearing equipment, and a body protective system.
>
> The system would protect against environmental, ballistic, flame, thermal, chemical/biological, detection and directed energy. Approximately 12-36 prototypes are expected for field demonstration.

There appears to be no technological necessity for tension between improved protection for an infantryman and his mission effectiveness. To be sure, the infantryman who wears the present issue ear-plugs impairs his auditory ability to perform his job. But he could well be issued one of the sets of sound-amplifiers commercially available to civilian hunters that both enhance the audio acuity of the wearer, and shield his ear drums from concussion.[11] Amplification of a soldier's human capability--more acute senses, aided strength, healthful comfort--as well as protection against battlefield threats, can and should be an objective.

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[10] *Defense Daily*, 12 January 1990. Cf., U.S. Army Natick Research, Development, and Engineering Center, Small and Disadvantaged Business Utilization Office, 99X004-90F.

[11] E.g., "Action Ear" stereo earphones available from Silver Creek Industries, P.O. Box 1988, Manitowoc, Wisconsin 54221; or the Van Sleek "FARFOON," available from The Dutchman, P.O. Box 12548, Overland Park, Kansas 66212. Both equipments list for around $150.

III. AN INFANTRY CENTER PERSPECTIVE

Analysts at the United States Army Infantry Center, Fort Benning, Georgia, acknowledge that many infantrymen will, in the future, have to fight encapsulated, that is, with their bodies buffered from a voracious battlefield environment.[12] They see two principal attitudinal hazards in encapsulation to be countered: (1) the prospect of creating a sense of isolation as opposed to integration with other soldiers, and (2) the likelihood of inducing a false sense of security and invulnerability in the soldier. For the soldier fighting on foot, the battlefield is not only mortally dangerous, but lonely. Infantrymen fight best when they fight with and for each other, as part of a team. In large measure, such a team is conceptual. However, any encapsulation scheme that breeds insularity could reduce each soldier's awareness of others. It could also, by walling him off from the real world, strip him of that instinctive wariness that has been one of the main protections of infantrymen in all ages.

Importantly, infantrymen have differing requirements for technological enhancements according to their battlefield tasks. For example, encapsulation for infantrymen who fight on or from a combat vehicle will have a lower priority than for those who fight afoot, and the needs of infantry commanders and infantry scouts are different from those of line troops (Table III-1).

Table III-1. Relative Priorities for Technological Enhancement (1 = first consideration; 4 = last)

	Individual Protection[a]	Combat Effectiveness[b]	C^3I[c]	Mobility[d]
Foot Soldier	1	3	3	3
Combat Vehicle Crewman	4	4	4	4
Scout	2	2	2	2
Commander	3	1	1	1

---

12 This section is drawn from remarks of Captain Leonhard, Department of Combat Developments, U.S. Army Infantry School, to a meeting of DARPA Program Managers, Rosslyn, Virginia, 8 December 1989.

A. LEVEL OF INDIVIDUAL PROTECTION

Table III-1 expresses notional differences in emphasis for improvements that reflect the fact that the mission of the line infantryman requires him to operate in the most lethal zone of the battlefield, and frequently demands that he forego the protection of mobility while providing fire support for moving team-mates or when defending against an advancing foe. Requirements for individual protection will also vary depending on the character of the conflict: there is likely to be a less demanding requirement for operations in combat with rural insurgents than with mechanized forces. Figure III-1 uses the construct of intensity.

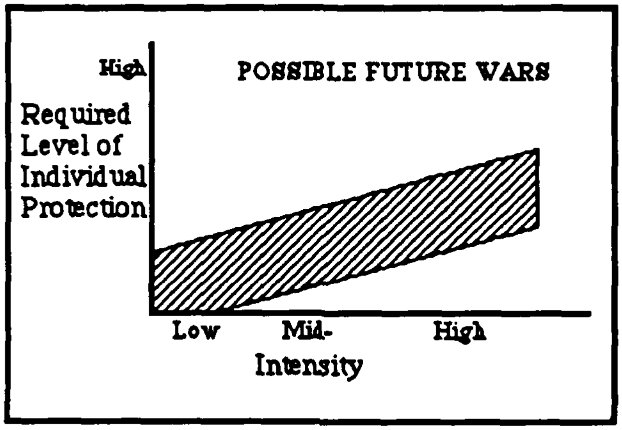

Figure III-1. Predicted Levels of Individual Protection for Future Wars

Certain infantrymen performing missions in low intensity conflict--for example, Rangers raiding a well-defended locality--might require levels of personal protection against threats from blast or kinetic energy penetrators much like those needed by infantrymen for high intensity warfare. But they probably would not need elaborate personal protection against chemical, biological, radiological, or thermal threats. This suggests modularity of design to permit some tailoring of battle dress to battle environment.

B. COMBAT EFFECTIVENESS

Combat effectiveness embraces total mission performance, including integration of ability to move, shoot, and communicate for specific military purposes; sustainability; and endurance. High intensity battle is expected to be short and sharp: decisive results in minutes or hours. Conversely, circumstances of low intensity conflict are expected often to deprive infantry of tactical initiative. Infantry combat is unlikely to be decisive in high intensity conflict, almost certain to govern low intensity conflict. In sum, technology that

improves infantry combat effectiveness probably would exert higher leverage in low intensity conflict than in mid- or high intensity conflict.

C. COMMAND, CONTROL, COMMUNICATIONS, AND INTELLIGENCE (C^3I)

Inherently, C^3I assets are more important to infantry commanders and leaders than followers, and, as adjuncts of personal equipment, more important to them and to scouts than to less mobile foot soldiers or to vehicle-supported crewmen. ("Intelligence" as used here refers not only to disseminated information about the enemy collected and analyzed elsewhere, but awareness of the surrounding battlefield environment derived from the soldier's own senses, suitably aided by sensors and processors embedded in his personal equipment.)

D. MOBILITY

Improved battlefield mobility has been the quest of most technological innovation applied to American infantry since World War I (e.g., jeeps, trucks, armored carriers, infantry fighting vehicles, helicopters, hovercraft, tilt-rotor aircraft). It is important to understand the differences among tactical, operational, and strategic mobility--the first providing for moving about the battlefield itself, the second for intra-theater movements, the third for inter-theater transport. Personal protection that merely increases the bulk and weight of each infantry soldier would clearly detract from all three. But personal protection that includes mechanisms making each soldier more agile, or speedy in a dash, even were these to add to his overall weight, would be of distinct advantage to tactical mobility, especially if the improvements could be attained without penalty for "mobiquity," infantry's ability to fight over any sort of terrain. Improvements in tactical mobility have in the past been attained at the expense of mobiquity, and of operational and strategic mobility. The challenge to technologists approaching encapsulation of infantry is to improve the effectiveness of each soldier and thereby to reduce the total number of soldiers required for any given mission, and thus to lighten the mission-weight of infantry units. Were it possible to reduce those numbers decisively, it might be possible to improve tactical, operational, and strategic mobility simultaneously. Hence, advanced technology developed to encapsulate the infantryman could constitute an intervention of crucial importance.

IV. ADVANCED CONCEPTS FOR DEVELOPMENT

On March 23, 1989, in separate but related high-level meetings in Arlington and in Leavenworth, participants underscored the importance of individual actors in future battle and of their training.[13] There was broad agreement that the Army required a means for injecting individual combatants onto SIMNET-like battlefields. There was consensus that DARPA and the Services, under the aegis of Advanced Distributed Simulation Technology, should move toward graphic representation of individuals and a capability to portray their tactical interactions with units or single vehicles--such as those of the artillery forward observer (FO), the MAW gunner, the MANPAD operator, and the commander on foot.

Up to the present, SIMNET has presented and tracked only icons representing land vehicles or aircraft. SIMNET is a distributed system in that there is no central computer directing the actions of all simulated entities. Instead, each simulated vehicle has its own microprocessor that communicates with all other simulators as required.[14] As more vehicle simulators are introduced into each "battle," each brings with it the computational power to support its own requirements. Each manned vehicle consists of a user interface with controls that replicate those on actual equipment, a computer image generator (CIG) color visual system, and a microprocessor. All vehicles at a given site are connected by an Ethernet local area network (LAN), that can handle up to 1,000 vehicles, and automatically corrects for errors. Each site has a small interface computer for communicating with other sites, and sites are interconnected by a long haul network (LHN), either high-capacity landlines, or satellite links. Vehicles communicate over the LAN or the LHN with the SIMNET Protocol, transmitting specially formulated information packets termed Protocol Data Units (PDUs). Each PDU characterizes, currently with a maximum of 256 bytes, the vehicle's location, movement, status, and appearance in relation to other simulated vehicles. New forms of simulators can easily be added, so long as each brings to the

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[13] The Leavenworth meeting was the Training Technology Symposium held under the auspices of General Thurman, Commander, TRADOC, for his School Commandants; the Arlington meeting took place at the DARPA SIMNET office. A MemoForRecord, dated 25 March 1989, is available, discussing both events.

[14] This description of the SIMNET is drawn from a MILNET message from Rolland Waters, dated February 1990, subject: "An Overview of the SIMNET Combined Arms Battlefield."

network its own computer of compatible power, and adheres to the Protocol. Inserting an individual instead of a vehicle into the simulation would require that a proper user interface be devised, that a CIG of appropriate size and weight be developed, that sufficient computing power be furnished, and that these be linked into a LAN or LHN. Research and development are clearly needed.

The Leavenworth discussions of R&D focussed on the encapsulated individual soldier. Encapsulation was postulated as necessary for survivability on future battlefields, whether of higher intensity--contaminated by CBR weapons and anti-personnel mines, and pounded by conventional explosives enhanced for blast overpressures, capable of rupturing the lungs or eardrums of unprotected soldiers--or lower intensity, where individual initiative and proficiency probably weighed more in the tactical balance. But even prototype encapsulation--already demonstrated, for example, by NASA (see the I-Port discussion, below)--would enable simulating sensory interfaces, including tactile emulators. In short, in a prototype of future battle dress, a soldier could be piped computer-generated sensory stimuli out of SIMNET, and he and other individual participants could be identified by an icon such as a miniature vehicle.

In Arlington, General RisCassi, Vice Chief of Staff of the U.S. Army, stated that if DARPA could, in its R&D, interrelate SIMNET, Leavenworth's Battle Command Training Program, and the Army's emerging Command and Control System, DARPA would advance the Army a long step forward to "where the Army has always wanted to be." IDA's Advanced Simulation Technology Facility proposed a proof-of-principle demonstration involving, first, Observation Posts, then anti-armor and anti-aircraft weapons fired by individual gunners.

The Leavenworth conferees also discussed the use of Training Developments to lead Combat Developments, especially to explore the man-weapon interface (MANPRINT), and the fit of the weapon to the combined arms team (what General Thurman, then Commanding General, TRADOC, termed FIGHTPRINT). While it is well understood that national security entails adapting advancing technology for military purposes ahead of any potential adversary, few military professionals appreciate the possibilities of speeding up the materiel development cycle through adroit use of training technology. Every manager of a weapon system development ought to appreciate what training technologists have thoroughly substantiated: ultimately the worth of any system will depend importantly on the humans who use it in battle. This truism can be stated in a mathematical paradigm:

$$E = f(W,P,T)$$

where:

E is effectiveness in combat

W is inherent weapon system capability

P is the proficiency of those who man the system

T is the tactic or technique of system employment.

The T parameter is seldom considered, but technologically well-founded systems (high W), in the hands of very proficient crews (high P), can be rendered impotent by an inept tactician (low T). The fact is that over the next two decades more and more armed forces throughout the world will acquire weapons of range and striking power entirely outside the experience of serving leaders. As General RisCassi pointed out, with SIMNET-like technology, the U.S. forces have a powerful new way of teaching tactics, i.e., by providing vicarious battle experience through which tactical commanders can learn to optimize the effectiveness of the weapons and the men in their charge.

Virtually all technology development programs accord first priority to materiel. If, during the execution of the program, there arises a need to reduce expenditures, the materiel is usually protected, and cuts are directed at "softer" parts of the program, of which training is usually regarded as "softest." The logic seems impeccable: development funds spent preparing to maintain the materiel, or to teach soldiers how to use the materiel, are moot until the materiel is in its final configuration, and the engineering "bugs" have been identified and ameliorated. Programs invariably proceed from materiel, to maintenance provisions, and finally to the training subsystem. Often, by the time training technologists become involved, most of the costs of the development have already been incurred (Fig. IV-1).

The President's Blue Ribbon Panel on Defense Management (the Packard Commission) cited this propensity to postpone methodical examination of the man-machine interface as a major flaw in U.S. procurement policy, and strongly recommended, as an antidote, a high priority on early prototyping.[15]

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[15] *A Quest for Excellence, Final Report to the President by the President's Blue Ribbon Commission on Defense Management*, 30 June 1986, pp. 55-57.

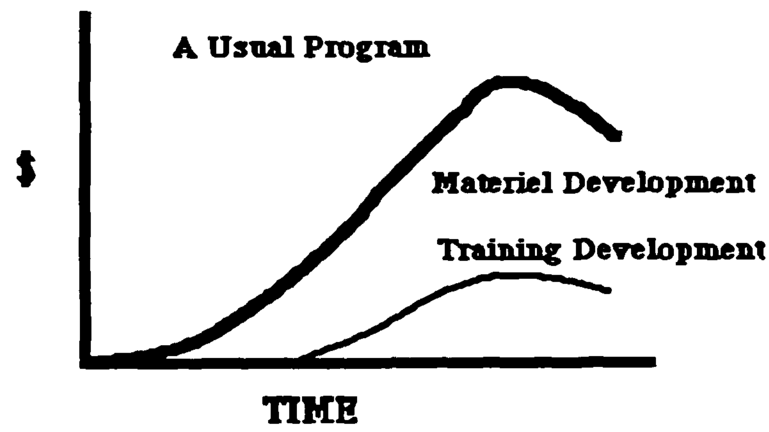

Figure IV-1. Typical Pattern of Program Material and Training Costs

In general, prototyping and testing in the early stage of R&D should be done by the service that would be the primary user of the resulting system. In order to promote the use of prototyping, however, we recommend expanding the role of the Defense Advanced Research Projects Agency (DARPA).

At present, DARPA conducts research and exploratory development in high-risk, high-payoff technologies. DARPA should have the additional mission of stimulating a greater emphasis on prototyping in defense systems. It should do this by actually conducting prototype projects that embody technology that might be incorporated in joint programs, or in selected Service programs. On request, it should assist the Services in their own prototyping programs. The common objective of all of these prototyping programs should be to determine to what extent a given new technology can improve military capability, and to provide a basis for making realistic cost estimates prior to a decision on full-scale development. In short the prototype program should allow us to fly--and know how much it will cost--before we buy.

Conventional prototyping is expensive, and, if flaws are discovered, time-consuming. Some Commissioners pointed out that training technologists had already demonstrated that bending metal is no longer necessary for achieving most of the goals of prototyping.

Responding to the Packard Commission charge, DARPA, in its SIMNET-D program, has already contributed a major technological advance in techniques for early prototyping.[16] The Defense Science Board (DSB), through its Task Force on Computer Applications to Training and Wargaming, commended DARPA's SIMNET as follows:

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16 Report of the Defense Science Board Task Force on Computer Applications to Training and Wargaming, Office of the Under Secretary of Defense for Acquisition, Washington, DC, May, 1988, pp. 28-29.

> Possible application of a new idea or breakthrough in technology via earlier acquisition of training prototypes is an effective way to explore future capability early. Based on tested training prototypes, the user can write better acquisition requirements, with more assurance that the acquisition could be more cost-effective. SIMNET is a success in this dimension....Taking full advantage of rapid training prototype technology is not always consistent with the current requirements-development and acquisition processes. Streamlining these processes and introducing the feedback advantages inherent in rapid prototyping can be effective in many acquisition arenas.

Members of the DSB Task Force noted that trainers perceive a prototype as a "simulation" of the eventual system, and DARPA's SIMNET-D has convinced more than a few training technologists that it is now possible to construct a digital model of a developmental system's functions, to embed this model in one or more plywood or fiberglass mockups, and then to try the system in virtual battle with soldiers operating the "equipment." The models, with many "men in the loop," can be used as a virtual prototype, to validate operational requirements for the eventual materiel's configuration, to gain understanding of how to train and evaluate crews, and to confirm the cogency of engineering designs. In instances where this has been done using SIMNET-D, defects became evident in what the end-user had asked for, in what the engineers provided, and in the tasks one or the other had imposed upon crew members. Importantly, virtual prototyping allows for quick, inexpensive revisions and reevaluation. Moreover, because of dense data-collection on all effectiveness parameters, the doctrinal implications of the prototype are easier to observe in virtual battle than they could have been in pure computer-based models of war, or in operational tests with an actual prototype.

Hence, the preferred allocation of resources for a development program would provide for virtual prototyping, and would be reflected in the curves in Figure IV-2.

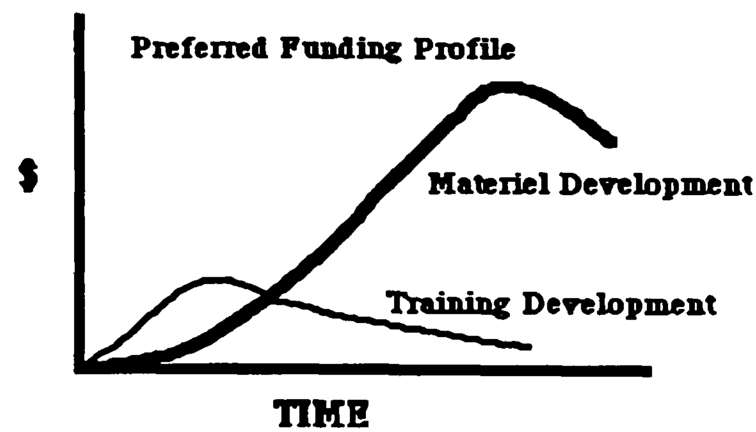

Figure IV-2. Preferred Funding Profile for a Development Program

V. I-PORT--INSERTING THE INDIVIDUAL INTO VIRTUAL BATTLE

One cannot contemplate a future for distributed battle simulation unless the technical problems associated with "seamless simulation" are solved. Readiness for future battle--especially low intensity conflict--will require that all the U.S. armed services have access to simulations for rehearsing the individual and collective skills required to meet the exigencies of battles ahead. In the following diagram, one of DARPA's visualizations, an individual portal into virtual battle, I-Port, is seen as essential for "seamless simulation," and an integral part of Advanced Distributed Simulation Technology.[17]

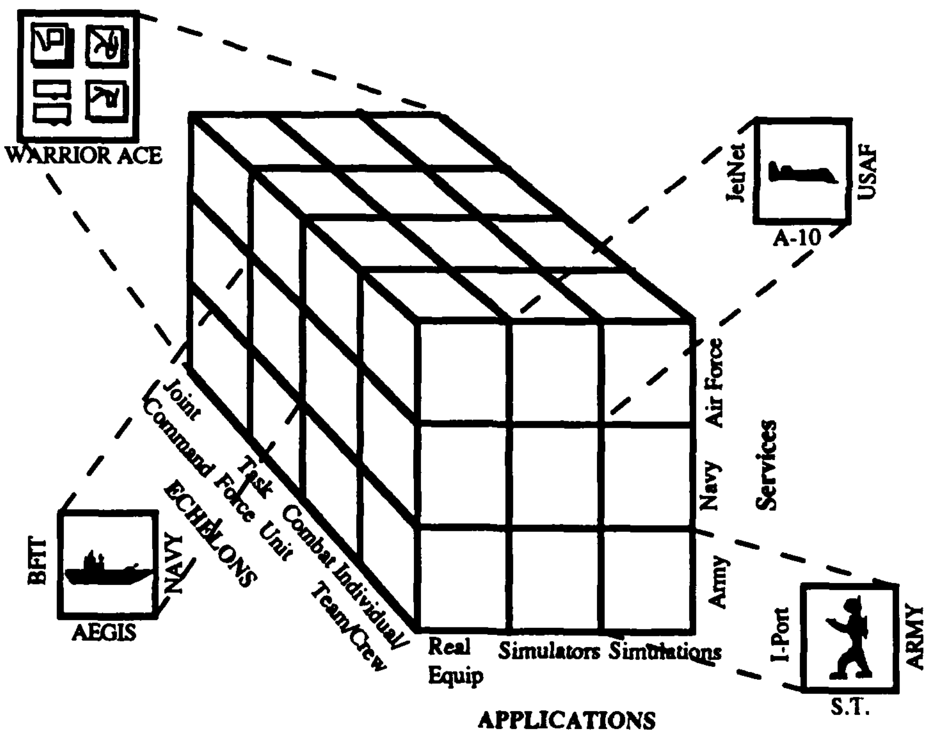

Figure V-1. Seamless Simulation: The need for standards for integrated warfighting common architecture of heterogeneous simulations with network standards across all Services at all echelons

[17] Diagram provided by the Advanced Simulation Development Facility, Institute for Defense Analyses, 8 December 1989.

The concept of I-Port is to use a head-mounted display to provide a "portal" into a "virtual reality." Such close-to-the-eye displays appear to be the most promising approach to projecting individuals into a situation for which visual and audio stimuli are generated by a computer.[18] A powerful, small, light, probably parallel personal computer would drive a CIG to portray the "world," a computer-generated environment, similar to that employed for SIMNET engagement simulation. The human eye commands a viewing angle that subtends 180 deg horizontally and 150 deg vertically. A viewer of a scene that fills the visual field perceives that he is within the scene, an illusion capitalized upon by the promoters of the IMAX and OMNIMAX motion-picture systems to their financial advantage. Hence, very large wall screens or a dome on which the viewer's surroundings are portrayed is one possible approach. But such large displays quickly outstrip cost-effective CIG, and appear indistinct, because at several feet viewing distance, a pixel might subtend two or more minutes, while the eye can usually discriminate detail down to one minute. Even up close, a CIG picture appears fuzzy: a high definition 20-inch square color monitor might display 4,000,000 pixels; at 2-feet viewing distance, each pixel would subtend ~1.4 minutes. A CIG monitor that fully exploits human visual acuity is yet to be built.

A head-mounted display provides each eye a slightly offset view of the same object, and thus induces stereoscopically the perception of depth. Other depth cues are provided by motion parallax--the shift in relative position within a field of view when an observer changes his point of view--and depth cues, taken together, aid the brain in interpreting what the eye sees. In short, the viewer may not be using all the eye's acuity, but he perceives that he is. Provided the CIG be informed of the position of the observer, it can portray precisely his field of view, and add to the credibility of the virtual environment.

The National Aeronautics and Space Administration, at its Ames Research Center, Moffett Field, California, has experimented for several years with a helmet-like display system called VIVED, which integrates technologies useful for I-Port and ST: speech recognition, three-dimensional sound cueing and speech synthesis, glove-like devices for

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[18] Foley, James D., "Interfaces for Advanced Computing," *Scientific American*, October 1988, pp. 127, ff.

tactile input and gesture tracking, computer image generation (CIG) and video.[19] The prototype is represented in Figure V-2.

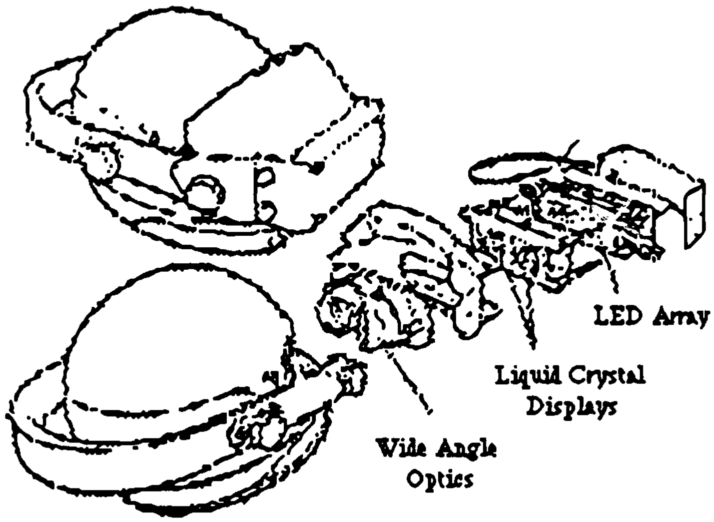

Figure V-2. Prototype of Virtual Visual Environment Display (VIVED)

The effective field of view is 120 deg for the horizontal and vertical, with a common binocular field of up to 90 deg presented through wide-angle stereoscopic lenses onto two high resolution 4-inch diagonal liquid crystal displays that can accommodate standard video signals generated by computer or video cameras. Images can be overlaid. Binocular parallax cues are derived from horizontally disparate viewpoints within a CIG data base, or from a pair of separated video cameras. The user can interact with what he sees through the gloves he wears. Head position and orientation are determined by a sensor manufactured by the Polhemus Navigation Sciences division of the McDonnell Douglas Corporation, and an eye-tracking apparatus informs the computer exactly where the eyes are trained.[20]

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19 Fisher, S.S., McGreevey, M., Humphries, J., and Robinett, W., "Virtual Environment Display System," paper presented to the ACM 1986 Workshop on Interactive 3D Graphics, October 23-24, 1986, Chapel Hill, North Carolina. Also, Fisher, S.S., "Virtual Interface Environment Workstations," presentation at the TRADOC Training Technology Workshop, USACGSC, Fort Leavenworth, Kansas, March 23-24, 1989 (NASA-Ames FL:239-3).

20 In the Honeywell Helmet Mounted Oculometer System (HMOS)--being purchased by the U.S. Army for its Visual System Component Development Program, and in use by the U.S. Air Force--an eye-tracking oculometer fixes the exact orientation of the eyes, and instructs the CIG to upgrade the granularity of its imagery specifically where the wearer is looking, leaving periphery and background less well-defined, thus reducing demands on the computer.

NASA's purpose was to use VIVED for telerobotics, enabling the user to take command of a remotely located robot--such as a machine operating in space--that would mimic his motions or respond to his voice commands (Fig. V-3).

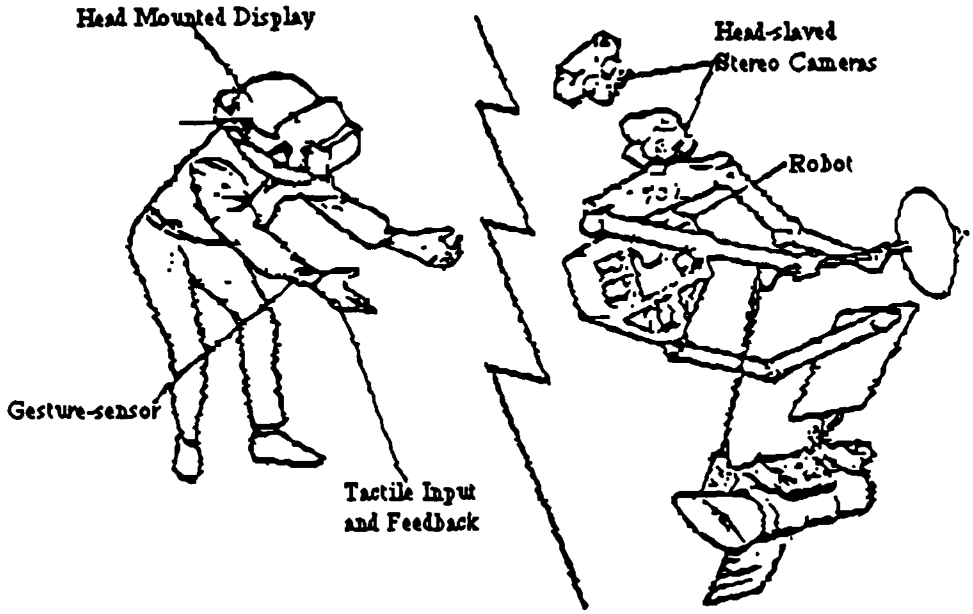

Figure V-3. Virtual Interface Enviroment, Telerobotic Control by "Telepresence"

Alternatively, NASA would have VIVED present to the wearer a virtual work station in the confines of a space ship that could make available to him a large-scale, integrated information management system. No computer hardware would have to be put into space, for the helmet mounted display would generate a control panel that the wearer could "touch" to summon a 360 deg array of various graphics, and interact with them by voice, gesture, or "touch".[21] In the I-Port concept, this application is described as "a commander's CP in a helmet," a means for providing a commander or battlefield leader, through a form of headgear, virtual presence within his command post (Fig. V-4). Alternatively, he could network with other leaders before an operation to rehearse tactics and techniques, and to prepare for contingencies. The same capability could be put to other difficult information management tasks (e.g., a master mechanic who needs access to extensive technical documentation while fixing armored vehicles forward on the battlefield,

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21 Fisher, S.S., op. cit.

or a physician's assistant who needs to summon to a battalion aid station the skills of a brain surgeon).

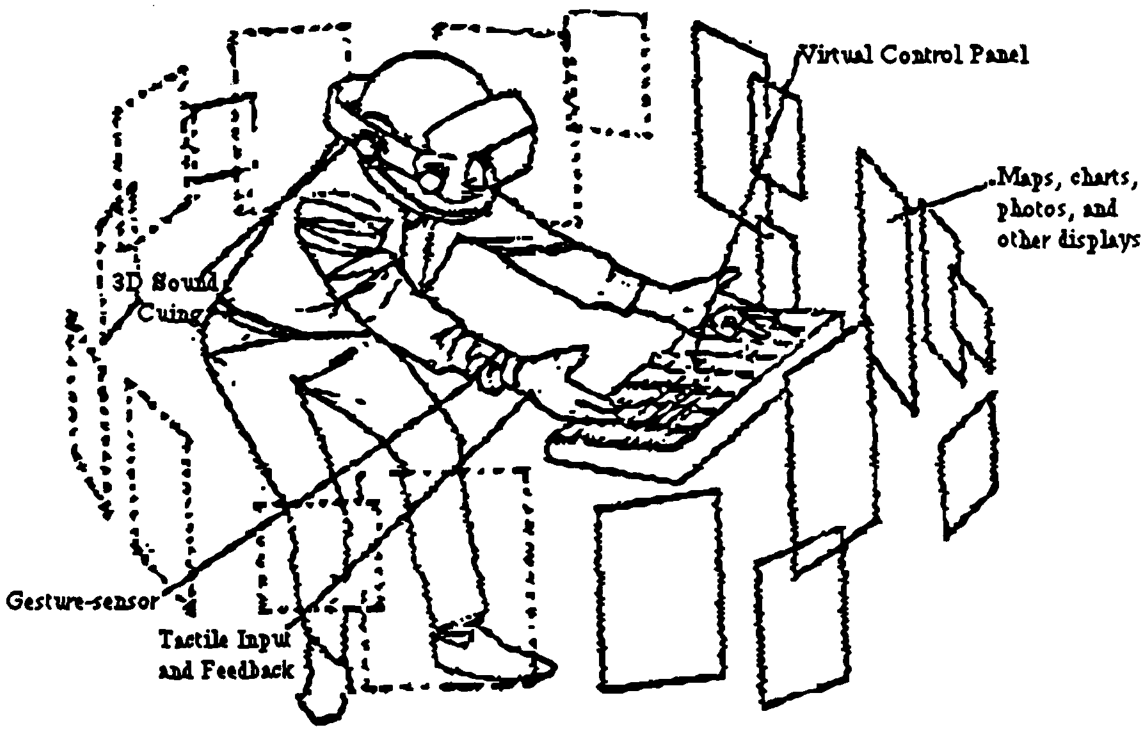

Figure V-4. A Command Post In a Helmet, Virtual Interface for C^3I

Among the devices described above are those that serve the sense of touch: tactile input and feedback. DATAGLOVE, developed by VPL Research, Inc., is a device that translates finger and hand movements into electric signals. Between two layers of cloth, fiber-optic cables run from the interface board to the end of each finger and back. A light-emitting diode is at one end of each cable, and a phototransistor at the other. When the finger flexes, light escapes, and the phototransistor converts the event into an electric signal. Figure V-5, below, depicts this apparatus.[22]

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22 Foley, op cit.

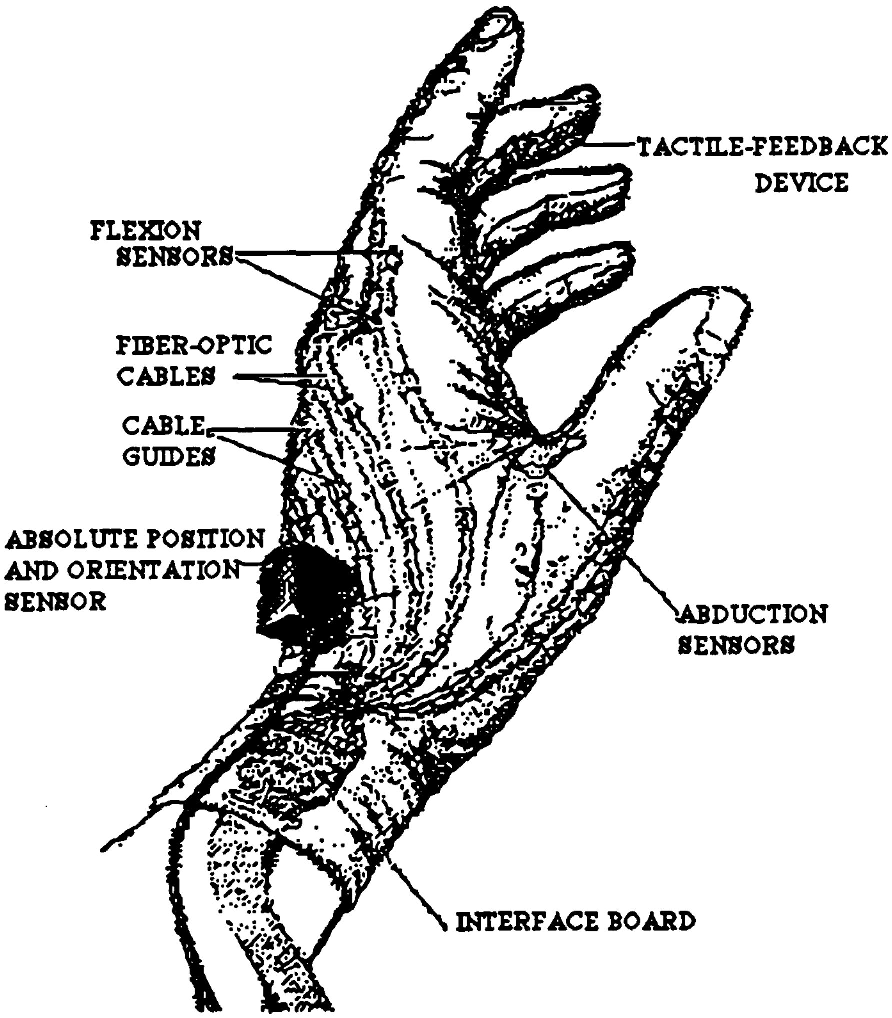

Figure V-5. DATAGLOVE

The position and orientation sensor shown is another Polhemus product. The tactile devices could be one of three types: small solenoids that push blunt wires into the skin, piezoelectric crystals that vibrate against the skin, or a "memory metal" that distorts, pressing against the skin, when electrically heated. The VPL development team, T.G. Zimmerman and L.Y. Harvill, have gone on to a fully sensored suit intended to cover the entire human body.[23] A full-body cover could incorporate all the several sensors--myoelectric, piezopolymer, intertial--for the soldier-exoskeleton interface; alone, it could be

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[23] On 21 January 1990, NBC "Sunday Morning" carried 10 minutes or so of Garrick Utley at VPL experiencing "virtual reality" while wearing DATAGLOVE and a head-mounted TV display. Cf., Zachary, G.P., "Artificial Reality: Computer Simulations in Future Promise Surreal Experiences that Users will 'Feel,' " *Wall Street Journal*, January 23, 1990, p. 1.

used to ascertain the individual soldier's musculoskeletal "signature" for inscription on his "dogtag."

Tactile sensation, however, does not equate to force. One of the force-feedback systems developed thus far is JOYSTRING, developed by R.J. Feldmann of the National Institutes of Health (Fig. V-6).[24] Each end of a rigid T is connected by three wires to computer-controlled servos, that exert force by differential tension. As the hand pushes or torques the "tool," it senses the latter's forceful interaction with the virtual environment.

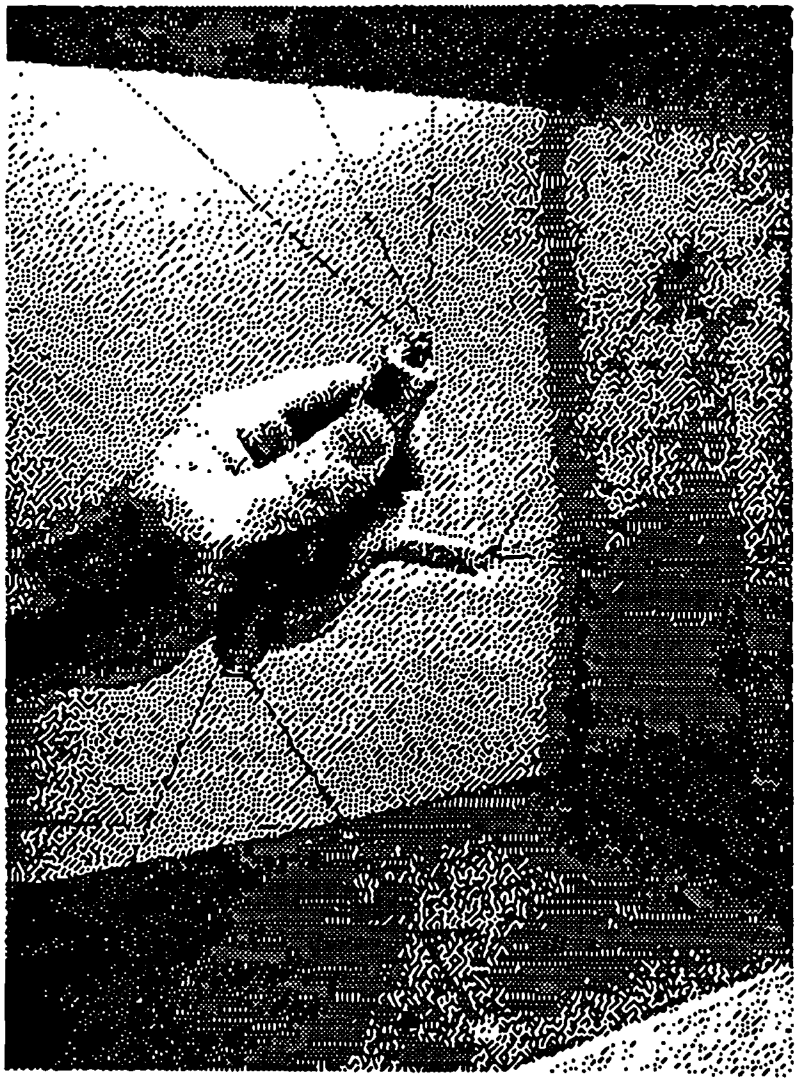

Figure V-6. JOYSTRING

24 Foley, op. cit.

A working hypothesis of the I-Port concept is that the prototype ST exoskeleton would provide an adequate force feedback mechanism for simulation. Each person networked in the simulation would wear whole body sensors, perhaps a DATAGLOVE-like undergarment, but would be strapped into an exoskeleton as well, with actuators at joints that could offer, when appropriate in the "virtual reality," resistance to movements as force-feedback. Moreover, the I-Port exoskeleton potentially can provide kinesthesia, the sensation of movement of the parts of the body.

Working exoskeletal arms with hands, incorporating excellent force feedback characteristics, have been built at the University of Utah. One Utah design is shown in Figure V-7.[25]

An exoskeleton is linked with a robotic arm. Force exerted on one is "felt" and reproduced by the other with high fidelity. The operator inserts his arm inside the exoskeletal master to take control of the pair, and thereafter the robotic slave replicates his arm and hand motions exactly. Force exerted against the slave limb is felt by the operator as force against his person. (The force feedback to the master, then, is in the form of electrical signals--which could be computer recorded, and regenerated.) Sensitivity is such that the manipulator can cause the robot to pick up and hold the compact disk, as shown.

The end purpose of almost all research into virtual reality cited above, including that at the University of Utah, has been to enable a man to control a machine operating in an environment hostile to humans--e.g., the ocean depths, or outer space--or in a microcosm or macrocosm apart from the user. The I-Port concept stands that idea on its head: I-Port will employ machines to control the man, at least in the sense of positioning him within a virtual military situation, providing him the sights and sounds that should trigger action, and enabling him to affect that situation by his actions and orders just as he would in comparable real circumstances.

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25 Information provided by Professor Stephen C. Jacobsen, Department of Mechanical Engineering, and Director, Center for Engineering Design, University of Utah.

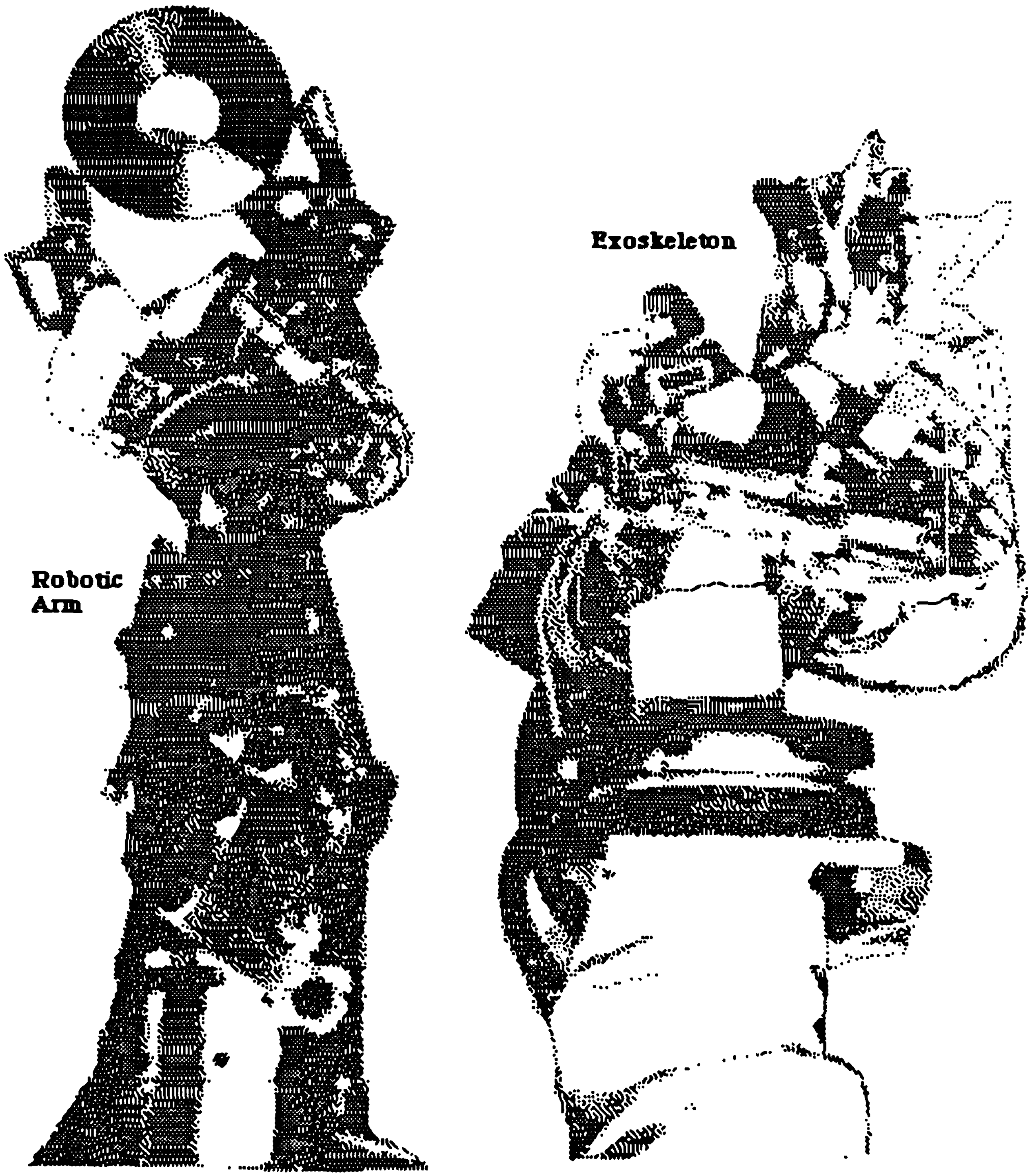

Figure V-7. Utah Arms

VI. THE JSSAP STUDY OF AN INDIVIDUAL FIGHTING SYSTEM

In 1987, the Joint Service Small Arms Program Office (JSSAP) contracted with Battelle Columbus Division to study the feasibility of a future individual fighting system. The design for this system assumed there would be significant additions to the soldier's load to provide better for his protection and effectiveness and that some form of powered exoskeleton would support the added weight. A notional system was described, and a development program planned for producing it (Fig. VI-1).[26]

> The notional Integrated Fighting System is a modular layered protective suit....The wearer will move about as though he is carrying no load through the application of an exoskeleton (which also provides armor protection) controlled by muscle-like actuators. As the wearer's arm moves, for example, sensors on his arm signal a computer which in turn transmits the proper command to the correct actuator....In the buttoned-up mode the wearer is in a totally enclosed and controlled environment with essential information continuously available from a heads-up display on his visor. A choice of pull-down visors provides different face and head cover; from open air, to full armor protection...the sketch...cutaway on the arm and the leg shows the muscle-like actuators under the armor plate...tubes...carry cooling or heating fluids...they also act as a tourniquet....The pack-like object on the back of the wearer provides connecting links....Medicines and drugs are also included....[27]

The conclusions of the Battelle study addressed both what could be done, and how to organize to do it, in the following:[28]

> It appears possible to develop such a system, within the risk tolerances identified with the various technologies, but not with present-day techniques and methods.

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[26] Tullington, B.J., Butz, D.J., and Hill, T.E., "A Notional Individual Fighting System," Report for JSSAP 10, U.S. Army ARDEC, Joint Service Small Arms Program Office, Dover, New Jersey, 25 August 1987.

[27] Ibid., pp. 12-16.

[28] Ibid., pp. 23-34.

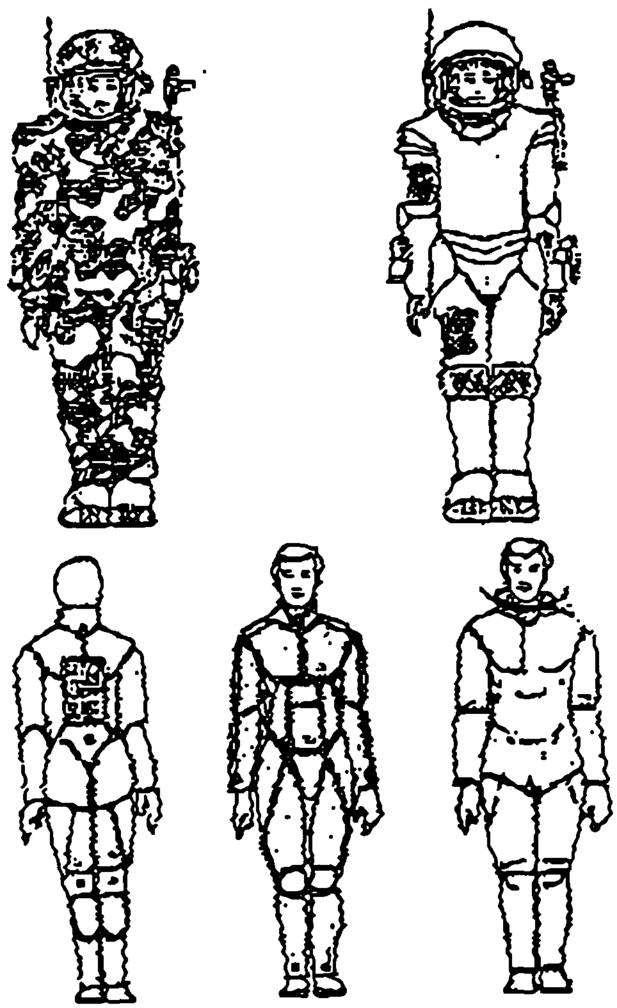

Figure VI-1. The JSSAP/Battelle IFS

Much work clearly needs to be done, and time will be required to mature both the technologies and the techniques. The user community must also be advised of the vast implications and potential capabilities such a system represents as these components evolve. This will permit the early integration of those components that have the highest operational payoff from the user's perspective.

It was also clear from our visits to the various Army RD&E Centers and Laboratories that these institutions are primarily engaged in finding solutions to the more near-term needs and deficiencies that are articulated in the several AMC and TRADOC requirements documents. It was also equally apparent that they were enthusiastically interested in the idea of a systems approach to the development of the individual combatant's fighting system, but not in taking the lead for the whole system. They saw their

> particular institution in a supporting role within the framework of their charter and areas of expertise. If there is to be such a system, however, there must be an agency or organization that can: monitor technological developments throughout the RD&E Centers, Laboratories, and industry; understand user needs, and coordinate and integrate this wide variety of activities. These actions cut across the traditional lines of responsibility and interest and involve the needs of more than one of the armed services. Within the framework of the DoD developmental system, it appears that an organization such as a joint program office, with a wide scope of responsibilities, should be established to perform these monitoring, integration, and coordination functions.

The report listed some 17 areas of technological risk, and estimated a time frame for development to resolve each. Those time frames ranged from 5 to 30 years, the average was 15-20 years. In short, the Battelle investigators would not expect enabling technologies to be on hand, even were a joint program office to pursue them adroitly, until the first decade of the 21st century.

VII. LANL--A FUTURE INFANTRY FIGHTING SYSTEM

The Los Alamos National Laboratory (LANL), operated by the University of California for the Department of Energy, is both more sanguine about the state of technology than the Battelle study group, and willing to act as the integrating organization. Drawing upon its experience with protecting humans operating in locations of nuclear hazard, with robotics, and with advanced materials, LANL has for several years considered a concept (referred to at LANL by its project code as PITMAN) for an infantry battle dress that would use robotics as a "man amplifier."[29] Dr. Moore, the chief LANL investigator, was acknowledged in the Battelle study as a seminal influence on its concepts and approaches.[30] His most recent LANL internal paper on PITMAN sketches a development with 18 major tasks commencing in FY 1989, aiming at an integrated prototype for evaluation in FY 1993. First-year expenditures were estimated at $7.7 million, ramping up to $16.4 in FY 1993, with a 5-year program cost estimated as $64.860 million (in FY 1989 dollars).[31] No action has been taken on this proposal, although the Laboratory has actively sought outside funding for it.

In the autumn of 1989, LANL reframed the PITMAN proposal as an infantry fighting system, and emphasized in a briefing a powered exoskeleton, full armor, integrated sensors, and low observables. The revision also embraced virtual prototyping. No cost estimates were advanced with the new packaging, but the present proposal seems to contemplate a more measured development, with an Initial Operational Capability (IOC) in the first decade of the 21st century. Importantly, however, LANL would reach IOC via a series of evolutionary steps, most of which would yield a usable product for the armed forces.

On 1 November 1989, a LANL team briefed PM SIMNET and PM TRADE in Orlando, Florida. On 2 November, LANL representatives presented their proposal at

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29 Moore, Jeffrey A., "PITMAN - A Powered Exoskeletal Suit for the Infantryman," Los Alamos National Laboratory, LA-10761-MS, June 1986.

30 Tullington, et al, op. cit., pp. 9-10.

31 Moore, Jeffrey A., "PITMAN - A Powered Exoskeletal Suit for the Infantryman," Los Alamos National Laboratory, January 1988.

Fort Benning, Georgia, to Major General Spigelmire, Commander, U.S. Army Infantry Center and School, who was accompanied by Colonel Burdett, his Director for Combat Developments. Since the apparatus proposed is essentially man-machine interface in its entirety, it lent itself well to the development strategy of virtual prototyping through SIMNET. LANL recommended that: (a) USAIC establish a requirement for a future infantry fighting system; (b) a program responsive to the USAIC requirement be concerted among the Army, DARPA, and Los Alamos National Laboratory; and (c) the program be presented to the Commander, USAIC for approval.

LANL presented its program objectives as shown in Figure VII-1.

Objectives: A Future Infantry Fighting System

- Hyper-mobility from strength supports and enhanced dash
- Integrated C^3I, with augmented and protected senses
- Weapons payload of at least 20 kilograms
- Rigid armor for head and thorax protecting from .50 cal
- Whole-body protection against fragments, blast, and flame
- CBR and electromagnetic protection
- Integral background-adaptive camouflage
- Suppressed infrared, acoustic, and radar signature
- Environmental conditioning for all-weather capability

Figure VII-1. LANL Program Objectives

LANL's proposals are not coextensive with AMC's SIPE; in particular, LANL may not have addressed adequately the urgencies and the difficulties of the threat from directed energy weapons to eyes and sensors (indeed, diagrams used in the LANL paper show a transparent helmet). Moreover, LANL may not have considered how to integrate its postulated "secure individual communication unit" with in-being or developmental military C^3I systems, nor did the laboratory try to show how its infantry fighting system would enhance cost effectiveness of an infantry unit (e.g., patrol/fire team/squad/platoon) performing tactical missions. Finally, LANL addressed no stated military requirement: it has promising technologies seeking a sponsor.

Nonetheless, the LANL concept is superior to SIPE in that while the latter focuses on protection, the former is both offensive and defensive, both functionally advantageous and protective. LANL's equipment would be useful for civil applications as well (e.g., for police, fire departments, and environmental safety workers). The Infantry Fighting System is a recommendation from a first-rank technical authority for a bold approach to solving a set of acute military problems, problems that in the uncertain world of the future can fairly be said to be of strategic importance for the United States.

The following table is reproduced from the LANL briefing (Fig. VII-2).

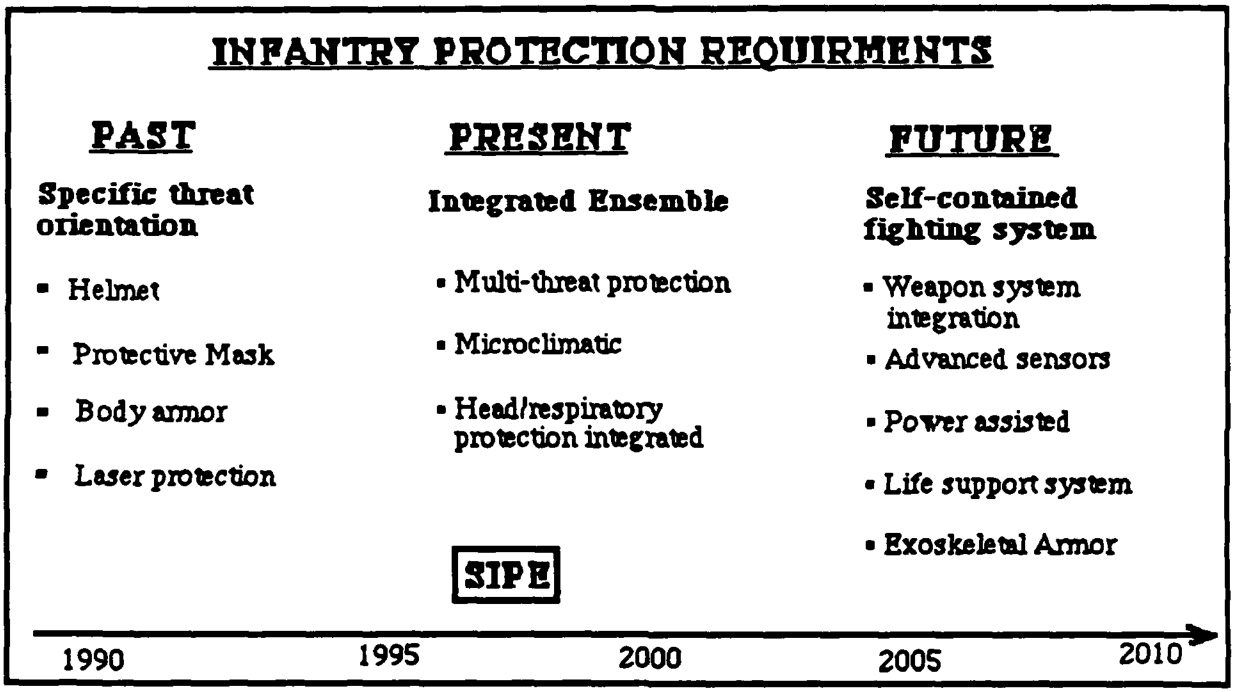

Figure VII-2. Infantry Protection Requirements of the LANL Program

On 28 November 1989, the USAIC Director of Combat Developments informed that a Letter of Interest in LANL's proposal would be forthcoming.[32] Further, he said that points of contact (POCs) had been established in the Technology Planning Management Directorate of Harry Diamond Laboratory in Adelphi, Maryland, and in the Long Range Planning Division of Natick Laboratory, Natick, Massachusetts. He characterized the POCs as "receptive."

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[32] A letter has been sent to LANL from the Director of Training Developments expressing interest in a portal into SIMNET for individuals.

That same date, Dr. Lance Glasser, one of DARPA's Program Managers, who had heard of the LANL proposal, expressed an interest in its implications for miniature computers embedded in personal equipment. He held that the characterization of the future computer as "a Cray in a soup can" has already been overtaken by developments within microchip technology, and that now it was possible to produce "a Cray in a soup spoon." He thought that the LANL proposal presented a number of opportunities for application of advanced, miniature, embedded computers, and indicated an interest in participating in any development program that might emerge.[33]

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33 Dr. Glasser sponsored, in January 1990, a conference on "Technologies for Personal Communications," in which he urged that the conferees meet to discuss personal, portable communications devices to focus on "what information technology support can make a person more effective."

VIII. OPERATION JUST CAUSE--
A NEED FOR SUPERTROOP?

Whether President Bush was right in resorting to the use of military force to unseat Manuel Antonio Noriega will no doubt be debated by historians for decades. Over the next several months, however, military leaders can expect critics in Congress and the media to press them hard in an attempt to discern the implications of Operation JUST CAUSE for future U.S. force structure, technology, and training. The Honorable Les Aspin, Chairman of the House Committee on Armed Services, has already notified the Speaker of the House that, because JUST CAUSE "points to the need for more thought about the kinds of forces and equipment our national defense will require in the future," he intends to form a subcommittee to conduct a more extensive inquiry into "lessons learned and their implications for U.S. military forces in the 1990s."[34]

Let's examine Operation JUST CAUSE to ascertain whether the advanced technology postulated above might have made a *difference* in either operational costs or effectiveness.

Congressman Aspin's assertion that JUST CAUSE typified the future deserves to be met with strong reservations. The operation was a remarkably smooth projection of military force from bases in CONUS to deal with one of the more compelling of those vexatious Third World problems that have plagued every President in the twentieth century. But there are only a few overseas trouble spots so prominent in American domestic politics--the Canal Treaty still rankles some voters--or so conveniently close to the bulk of the U.S. forces in strategic reserve. In Panama, there were forward deployed 13,000 U.S. troops and a substantial amount of heavy equipment--including Sheridan tanks and other light armor, Apache helicopters, and AC-130 gunships--literally within sight of most key objectives, securing an elaborate complex of bases and communication facilities. Assault units had weeks to prepare--in some instances, to rehearse--their role in the operation.

The concept of the operation was a *coup de main*. XVIII Airborne Corps, reinforced by Rangers and other Special Operations Forces, in coordination with attacks by

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[34] L. Aspin, letter to Honorable Thomas S. Foley, January 11, 1990.

U.S. forces in Panama, pounced in the dead of night on 27 targets simultaneously. About 4,500 combat-laden paratroopers, some flying as far as 3,500 miles, hit drop zones amid built-up areas, often where Panama Defense Forces could be expected in strength. Infantry and armor attacked the headquarters of the Panama Defense Forces, supported by a base of fire literally at the doorstep of USSOUTHCOM. As expected, casualties ensued. Most of these were sustained early in the operation, which proceeded in three phases: (1) assault, (2) movement to control, and (3) stabilization. The first phase was the most costly, and most of the losses during the assault were among infantry and related to insertion (i.e., Rangers and other paratroopers jumping with heavy combat loads from low altitude, at night, into contested drop zones or troops detrucking). Casualties dwindled rapidly during the second phase, and were rare in the third. Throughout the operation, Army infantry units, overwhelmingly more numerous than those of other branches or Services in the danger zones, absorbed most of the losses; injury, as opposed to ordnance, was the usual cause for evacuation.[35]

As was also expected, the American news media promptly put President Bush and General Maxwell R. Thurman on trial, and tolled the mounting casualty figures hour by hour to the public, as though thereby to measure the effectiveness of the operation. There were 23 fatalities;[36] wounded and injured were upwards of 300.

The preliminary data on U.S. Army casualties were drawn from two sources: doctors in USSOUTHCOM, and the CONUS hospitals to which the wounded were evacuated. The SOUTHCOM figures showed that of some 290 individuals evacuated from Army combat units, 15 were KIA, and 275 WIA; the percent KIA/WIA, 5 percent, is comparable to U.S. Viet Nam experience, and to that of the El Salvadoran Army in 1985. Of the evacuations of living soldiers, 44 percent were for wounds from fragments and bullets, and 56 percent for fractures or other injuries. Losses of 290 amount to about 1 percent of the total force in Panama, about 4 percent of the Army combat forces committed--over 6 days, ~1 percent per day; the latter is less than Israeli losses in 1973 (2 to 3 percent per day), but runs about the same as U.S. experience in mid-intensity warfare in Korea and World War II (~1 percent per day).[37] Hence, Operation JUST

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35 "Operation Just Cause-Panama: Casualty Data Analysis," Center of Excellence in Military Medical Research and Education, Office of the Surgeon General of the Army and Walter Reed Army Medical Center, 11 January 1990 (COEMMRE). This paper is based on "Preliminary Data: Subject to Confirmation...approximations of casualty patterns."

36 Ibid. Autopsies took place, but results have not been made available.

37 Ellis, op. cit., pp. 155-189.

CAUSE, at least in its first phase, should not be regarded as an instance of low intensity conflict--a judgment with which certain Panama Defense Force personnel, then shocked by very intense bombardment, would, no doubt, readily agree.

U.S. casualty data from CONUS hospitals reported on 225 cases with 267 instances of injury, of which only 14 percent were inflicted on regions of the body protected by Kevlar armor, while 86 percent were inflicted on exposed body regions. Anecdotal amplification of the data from interviews of patients suggests that a number of the ordnance-casualties might have been avoided (e.g., caused by not wearing protective equipment, or wearing it improperly). Interviews also pointed to some instances of amicide (friendly fire). No authoritative numerical data on these phenomena are available. (Probably heat and humidity should be cited as causal factors, not only of heat prostration, but heat-induced tactical torpor and lack of tolerance for protective equipment.)

But fractures were more common than ordnance-induced injury: trauma-related injuries comprised 50 percent of the total cases, while munitions-related injuries comprised 39 percent. Most injuries occurred in the leg region: 71 percent due to trauma, 27 percent to ordnance. Ankles were the most vulnerable: over half of all lower limb injuries were fractures or sprains of the ankle. Some 2-3 percent of those soldiers who parachuted into Panama sustained jump injuries, twice to three times what is considered normal in a daytime training drop. Insertion took place in darkness, usually from an altitude of 500 feet, into cluttered areas of cement, asphalt, and cinder block; troops were heavily laden. Similar trauma was reported among light infantry deploying from trucks in rubbled parts of the city.

Baseed on the above, to prevent or to reduce casualties in future contingency force-projection operations, technologists should address the following goals:

- To improve resilience and strength of the lower limbs.
- To protect the body regions beyond cranium and thorax.
- To provide thermal conditioning of the battle dress.
- To reduce casualties from friendly ordnance.
- To insure more timely medical response to casualties.

A. EXOSKELETAL SUPPORT

For a number of years, officers of the Army Medical Corps have been urging adoption of an orthopedic brace to reduce instances of trauma to the lower limbs during

parachute landings; the Panama experience underscores the cogency of their recommendations. Such a brace might be entirely passive, as described in the following statement of requirements recently drawn up by the Surgeon General's Center of Excellence in Military Medical Research and Education.[38]

Airborne Exoskeletal Reinforcement System

Current policies require airborne units to be able to parachute from low altitudes with heavy soldier loads. Casualty evidence from the Panama conflict has indicated a significantly high incidence of jump-related casualties. The majority of these injuries were musculoskeletal system injuries involving a variety of trauma to the lower limb.

In these types of combat operations, in particular when parachuting occurs at nighttime, added protection to the lower limb would likely prevent the trauma injuries observed.

Design Parameters

Design and develop an exoskeletal reinforcement unit for the lower limb, light in weight, yet capable of buffering the forces placed on a limb at landing impact. The airborne exoskeletal reinforcement unit (AERU) would be designed to be expendable. After landing, the AERU could be discarded quickly by the strategic unlatching of the attachment system.

The AERU would reinforce the primary joint system areas in the distal limb, the ankle and knee joints in particular. The incidence of ~69% of all lower limb injuries in the Panama casualty data occurred at the three primary joints: the hip, knee and ankle, of which ~92% of these joint injuries occurred at the knee and ankle; ~73% of all joint area injuries occurred at the ankle. If sprains and other musculoskeletal trauma is factored into lower limb injuries data analysis, ~71% of all injury to the lower limb occurred from this type of classification, in contrast to fragmentation munition injury, an incidence of ~17%, and gunshot injury, an incidence of only 11%.

In addition to joint system reinforcement, vertical vector force impact resistance should be developed to prevent long-bone fractures.

The development process should involve a careful preliminary anatomic evaluation of jump stress points and integrate these data into the design of a lightweight AERU. A prototype should be assembled, tested and further evaluated for its reliable safety and routine use in low-altitude jumps.

The Center for Excellence (COE) has formed an expert orthopedic study group with previous investigative experience in extremity, and in particular joint region protection. Medical science based recommendations and

38 Center of Excellence, 16 January 1990.

specifications will be reported. The COE will act as the advisory and directive body in the vendor development of AERU.

The drawback with a passive, brace-like device, such as the proposed AERU, is that soldiers, particularly soldiers under fire, are likely to need more assistance. They face not only landing-shock, but the strength-debilitating effect of fear. Hence, the design might better be active, powered, and computer-controlled, as proposed for the exoskeletal subsystem of ST/I-Port. The members of the exoskeleton might be very light structure of a composite material like graphite epoxy, and take full advantage of recent advances in small, powerful actuation systems.[39] A powered exoskeleton for the legs and pelvic girdle only (provided it were properly coordinated with the wearer's load-bearing equipment) may suffice, especially for a ST/LIC (SuperTroop/Low Intensity Conflict) ensemble, adequate in threat environments such as that troops faced in Panama.

There are a number of advantages to a powered exoskeleton for assault parachute landings, not the least of which is its potential ability to assist the wearer in carrying large loads off of a fire-swept drop zone without having to stop to unlatch, as with the AERU described above.

S.L.A. Marshall put the issue succinctly to any CINC who might in the future be contemplating a JUST CAUSE-like projection of forces from CONUS:[40]

> On the field of battle man is not only a thinking animal but a beast of burden. He is given great weights to carry....Rare indeed is the high commander who will fight consistently and effectively for the opposite. In fact, it is chiefly the high commanders who have laid this curse on the back of the fighting man right down through the ages....

Marshall's interviews of participants in the Normandy landings led him to conclude that overloading of OVERLORD's assault infantry was a primary cause of casualties on the beaches. He wrote:[41]

> In the measure that the man is shocked nervously, and that fear becomes uppermost, he becomes physically weak. His body is drained of muscular power and of mental coordination. For these reasons, every extra pound he carries on his back reduces all his tactical capabilities.

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39 Moore, op. cit. Jacobsen and Woods, "Micro Electro Mechanical Systems (MEMS)," Draft DARPA Report, Center for Engineering Design, University of Utah, January 23, 1990.

40 Marshall, Col. S.L.A., *The Soldier's Load and the Mobility of A Nation*, Washington, DC, 1950, pp. 7-10.

41 Ibid., pp. 42-45.

Said Pfc. Hugo de Santis:

'We all knew we were carrying too much weight. It was pinning us down when the situation called for us to bound forward. The equipment had some of us whipped before we started. We would have either dropped it at the edge of the beach or remained there with it, if we had not been vigorously led.'

Said Lieut. John S. Cooper:

'A few of the men were so weak from fear that they found it physically impossible to carry much more than their own weight. So the stronger men took the double risk of returning and helping the weaker men to move their stuff across the beach.'

Said Serg. Bruce Heisley:

'We were all shaky and weak. I was that way though I had not been seasick during the ride in. In fact, I didn't know my strength was gone until I hit the beach. I was carrying part of a machine gun. Normally I could run with it. I wanted to do so now but I found I couldn't even walk with it. I could barely lift it. So I crawled across the sand dragging it with me. I felt ashamed of my own weakness, but on looking around, I saw the others crawling and dragging the weights they normally carried.'

Said S/Sgt. Thomas B. Turner:

'We were all surprised to find that we had suddenly gone weak, and we were surprised to discover how much fire men can move through without getting hit. Under fire we learned what we had never been told--that fear and fatigue are about the same in their effect on an advance.'

Marshall's prescription was to reduce the infantry battle load to no more than 40 pounds, that for assault troops to be even lighter. But his essay is a brilliant evocation of all the urgencies and misconceptions within any military bureaucracy that lead to precautionary burdening of the troops--including the soldier's ignorance of his own best interests. Moreover he wrote unaware of the incremental weight entailed in body armor, night vision goggles, and other modern fighting gear.

Some technological intervention is required, and the means appears to lie in a powered exoskeleton. In the 1960s, General Electric experimented with a powered

exoskeleton,[42] and more recently DARPA has fielded a man-piloted land vehicle with six articulated legs.[43] The French are reported now to be operating a powered exoskeleton for the purpose of manhandling heavy or dangerous materials, but at this writing, little is known in DARPA about its design or capabilities.[44]

The key technical issue is how to power the exoskeleton. Conventional power supplies are patently too bulky and heavy to be man-portable and sustainable. Before an effective exoskeleton can be built, a novel source of power, one furnishing something like 1 kW of power for each kilogram of weight, will have to be developed.

It seems evident, too, that an exoskeleton will require a very powerful computer. The ST exoskeleton will have to respond to the complex and intuitive dynamic movements of a wearer who must move with agility across rough terrain. Unlike a prosthetic device, the exoskeleton would not provide the primary motive power, but would act as a strength inducer, lending its power to preserve the wearer's unencumbered speed and grace. The exoskeleton's motions would have to be monitored continuously to maintain the balance of the entire man/machine system, and to react instantaneously to myographic cues from the wearer signaling initiation of a motion, gesture, or weight-shift. In effect, the machine would have to "learn"--be programmed for--the range of muscle/actuator correlations that would comprise the musculoskeletal "style" or "signature" of each individual soldier. LANL has proposed recording this individual program on a chip embedded within the soldier's identification tag--his "dogtag"--worn on a chain around his neck.[45] When a soldier donned his ST battle dress, he would insert one dog-tag into a slot under the chest-armor, thereby loading his personal program into the battle suit's computer. I-Port can

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42 Known to some as the "Elephant Man Project," this program was funded by the Chief of Ordnance, U.S. Army, Lt. General Hendricks, and monitored by John D. Weisz, presently Director of the Army's Human Engineering Laboratory. Research was conducted at General Electric's General Engineering Laboratory, and concluded at the Corporate Research Laboratory, Schenectady, New York. Researchers included W. Gray, N. Wood, and R. Moser. About that time, GE also fabricated a quadriped walking machine. One source of information on these projects is Professor Robert McGhee of the Computer Sciences Department, Naval Postgraduate School, Monterey, California, formerly with Ohio State University.

43 The Adaptive Suspension Vehicle (ASV), developed by DARPA at Ohio State University under the Program Management of Dr. Robert L. Rosenfeld. Defense Advanced Research Projects Agency, *Robotic Manipulators and Legged Locomotion*, Arlington, Virginia, 1988.

44 Source is a second-hand report from participants in NATO R&D Subcommittee 3, under the leadership of the Joint Small Arms Office at Picatinny Arsenal. A request has been made of Col. Thorpe, DARPA's EUCOM Office, to obtain more definitive information.

45 Moore, op. cit., p. 8.

explore in depth various approaches to designing a workable exoskeleton and assuring its control.

There is an important related objective for developing an exoskeletal support system: if successful for military operational purposes, its mechanisms can be adapted for improved prostheses, not only for combat veterans, but for millions of non-functional or feeble victims of disease or civil trauma. The Center of Excellence at Walter Reed Army Medical Center has recognized this prospect.

B. ENHANCED BODY ARMOR

During World War I, American forces adopted the British-style rimmed helmet, and in World War II, the indigenously-designed "steel pot" with liner. During the Korean War armored vests were issued to infantry, and in South East Asia a few armored trunks and boots were employed as counter-mine measures. The advent of fabric-like materials, such as the para-aramid Kevlar (produced by E.I. Du Pont de Nemours & Co.), led to new, lighter and more wearable designs.

In Panama, Kevlar helmets and vests--referred to by the Army as PASGT, Personnel Armor System for Ground Troops--were the main protection. It should be noted that the Panama casualty studies do not treat instances in which the body armor averted a casualty or ameliorated a wound. Inferentially, PASGT helped, in that ~85 percent of wounds and injuries occurred in parts of the body other than protected areas. However, the quest for effective protection against ballistic threats is far from over.

World War II data on battle deaths, from both British and U.S. records, remarkably consistent across all theaters of war, show that the head and the chest are vulnerable, and that hits there tend to be fatal more often than hits taken elsewhere. In Viet Nam, 9 out of 10 fatalities were caused by hits to the head or thorax--hence, current U.S. body armor.

Research at the Los Alamos National Laboratory points to prospects by the year 2000 of encasing cranium and thorax with armor formed of spaced composites that would protect against a .50 caliber round, and weigh about 6 pounds per square foot. Promising materials are ceramic-particulate-reinforced aluminum, whisker-reinforced metal or ceramics, and ceramic-loaded polymers. More compact materials, such as laminated

ceramics, are also possible at ~30 percent more weight.[46] Lighter, more efficient body armor is also being investigated by the Army Materiel Command, which reports that there are several fibers that offer levels of ballistic protection at least equivalent to Kevlar with 20 to 30 percent weight reduction [e.g., Spectra, a high-modulus polyethylene fiber (Allied-Signal, Inc.), and PBZT, polybenzthiazole, a U.S. Air Force development from its ordered polymers research program]; these can be fashioned into fabric or rigid armor.[47]

But wound statistics reveal that the whole body is at risk. In World War II, where artillery-inflicted casualties predominated, fragment wounds were more common in the upper body, and bullet wounds were more usual in the lower limbs. In more recent U.S. data from Viet Nam and Panama, that relationship has shifted, probably because of PASGT: wounds of the extremities, particularly the legs and feet, have become increasingly likely. In JUST CAUSE nearly three-fourths of all ordnance-caused wounds were to the extremities; 37 percent of gunshot wounds and 79 percent of fragmentation wounds were to legs and feet--a *prima facie* case for lower limb armor.

Table VIII-1 compares U.S. Army experience with British experience from World War II in El Alamein and North West Europe.[48]

Table VIII-1. Percentage Distribution of Penetrating Wounds by Body Region and Ordnance Type

	Head & Neck		Trunk		Arms & Legs	
	GSW	Frag.	GSW	Frag.	GSW	Frag.
NW Europe, WWII	18	11	12	10	47	62
Alamein, WWII	26	13	15	15	48	63
Bougainville, WWII	29	24	24	22	47	54
SW Pacific,. WWII	21	19	31	30	48	51
Viet Nam, 1967-1969	33	21	31	24	36	55
Panama, 1989	9	5	18	21	73	74

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46 Ibid., p. 5.

47 Cf., *Army*, October, 1989, p. 402.

48 U.S. Army data for Panama, Viet Nam, Southwest pacific (Campaigns in New Georgia and Burma), and Bougainville Campaign provided by the COEMMRE, 23 January 1990. British data for El Alamein and North West Europe is taken from Ellis, op. cit., p. 179; no reason is given why latter data do not add to 100.

The recent incidence of wounds in exposed body regions is more than three times that for regions now protected by PASGT. These statistics alone underwrite ST's objective of extending armor protection over the entire body. Kevlar materials and football player-like "pads" of rigid armor or plates could be fitted to the limbs, and boots with armor components to the feet.[49]

There is another body region beyond PASGT that may be at increasing hazard: the eyes. Half of all weapons-related accidents during U.S. Army peacetime training are eye injuries from fragments moving at slow to moderate speeds.[50] While the available survey of the Panama experience reports only a few instances of eye injury, or informs anecdotally of opthalmic damage, 9 percent of total U.S. combat injuries in Viet Nam were to the eyes, and Israeli battle experience, from about the same era, was as high as 10 percent in certain localities (Table VIII-2).

Table VIII-2. Eye Injuries as a Percent of Total Combat Wounds[a]

War	Years	Percentage
WWI	1914-1918	2.1
WWII	1939-1945	2.0-4.1
Korea	1950-1953	5.0-8.0
Viet Nam (U.S.)	1964-1974	9.0
Six-Day War	1967	5.6
Yom Kippur War	1973	7.6

[a] Source: Belkin, M., "Opthalmological Lessons of the 1973 War," June 1977, cited in *Armor*, July-August 1985, p. 25.

The data in Table VIII-1 point to a requirement to incorporate into the ST helmet some form of ballistic protection for the eyes. Eyes will also have to be protected from lasers, and this in turn could dictate a lengthened optical path to permit sensing potentially damaging incoming radiation, and activating a block before it reaches the retina, or the focal plane array in front of the retina.

To recapitulate:

- In JUST CAUSE-like operations of the future, measures aimed at *casualty-reduction* will have a high political payoff, as well as obvious military utility in keeping assault troops pursuing mission.

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49 Moore, op. cit., p. 5.

50 "Protective Eyewear," *Army*, January, 1988, p. 67.

- *Injury-avoidance* ought to become an objective for research and development for contingency forces, especially Special Operations Forces and other assault troops especially vulnerable to hostile ordnance.

C. THERMAL CONDITIONING

Whole body armor alone, without measures to compensate for the additional weight and heat-loading, would be resisted by sensible soldiers who would have to fight in it. Hence, ST's incorporation of a powered exoskeleton and mechanisms to maintain the temperature of the costume at tolerable levels. As any soldier knows, the heavier his load, the greater his exertion, and the more he sweats. Heat dissipation from the average male is about 70 watts at rest, but rises to ~ 500 watts with exertion.[51] Overheating can occur rapidly while moving about heavily laden in a tropical country like Panama, especially wearing the PASGT; fatigue sets in quickly, and the ability to manage body fluid efficiently is seriously taxed.

The SIPE program's exploration of a soldier-portable conditioner deserves to be pursued with vigor. Los Alamos National Laboratory has been investigating a family of applicable fuel cells, such as a hydrogen/air cell with battery back-up, that could drive the conditioner and simultaneously generate oxygen for the wearer from his "canteen."[52] Both the AMC and LANL approaches have been aimed at full protection against chemical, biological, and radiological weapons, a more demanding environment than that likely to be encountered in regional contingencies like JUST CAUSE. And AMC's SIPE adds to the soldier's load uncompensated by exoskeletal support, as in the LANL proposal.

A more promising approach would be to combine SIPE with an evolutionary approach to ST, evaluating SIPE components individually and collectively via I-Port, and using some or all of them in the eventual ST design. A tailored design ought to be possible, so that the ST-version could be issued to troops going into action afoot in a Panama-like threat environment--what might be referred to as ST/LIC, to distinguish it from more ample protection designed for mid- or high-intensity warfare involving lethal chemical, biological, or radiological weapons. More than protecting the soldier, the ST concept is designed to amplify his physical strength and sensory acumen, proposing both a powered exoskeletal support system and a "smart helmet" with built-in enhancements for sight and hearing.

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51 Moore, op. cit., p. 4.

52 Moore, op.cit., p.6.

D. REDUCED AMICIDE

A "smart helmet" appears to offer a countermeasure for amicide. "Friendly fire," "fratricide," or "amicicide"--terms describing casualties accidentally inflicted by one element of an armed force upon another of the same force--is scarcely a new phenomenon. The British military historian, John Keegan, has described instances of it during the Battle of Waterloo, and attributed one-fifth of British battle deaths in the Crimean War, and one-seventh in the Boer War to accidents. He believes that modern armies are even more accident-prone. Keegan concludes that: "Some attempts have been made to calculate the proportion of accidental deaths to all death in battle. Attempts they remain, but the evidence is unarguably demonstrative of a very high level of accidental death in warfare."[53]

In the U.S. Army, amicide has certainly constituted some portion of battle casualties in all wars, and modern ordnance and mobility has increased the vulnerability of U.S. troops to "friendly fire." Combat veterans of Viet Nam were all too familiar with "artillery accidents" and "mechanical ambush accidents"--the latter referring to a U.S. soldier running afoul of one of the trip-wired Claymore mines often used on trails or on approaches to defensive perimeters. Moreover, as U.S. forces have become mobile in three dimensions, the difficulty of coordinating fire and maneuver has outstripped advances in command, control, and communications (C^3). Records of engagement simulation at the National Training Center, Fort Irwin, point to amicide as a factor in as much as 25 percent of putative combat losses there. The reported amicide in Panama, whatever fraction of casualties it represents, should spur Army efforts to improve C^3, for effective force in a future objective area could thereby be increased by that fraction.

Two technologies, both fielded relatively recently, appear to offer relief: one is precise personal position-fixing and navigation aids, and the other is display technology capable of transforming digital planar maps to present a perspective from any particular point of view. A solution to the amicide problem would be to pinpoint, on command, the location of every friendly soldier in a given area of the battlefield, and to provide an *in situ* evocable record of mine, booby traps, and "mechanical ambushes." Locational data could be either absolute, such as that derived from a Global Positioning System (GPS) receiver, or relative, such as that from an inertial navigation system or a Position Locating and Reporting System (PLRS). Now that GPS is available, the most cost-effective approach appears to be helmet-embedded GPS modules, and "minefield markers," small, GPS-

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[53] Keegan, John, *The Face of Battle*, New York, 1976, pp. 192-194, pp. 311-313.

equipped, black boxes that could be off-set from the ordnance to locate it for friendlies. Data from these devices--suitably encrypted and protected from intercept--would prompt display of an icon representing each "friendly" hazard within the helmet-mounted viewer of any soldier about to deliver direct fire, to adjust indirect fire, or to initiate movement into an area possibly mined. Required would be a network of personal computers and personal communication sets that could, on demand, define, encode, and transmit packets of relevant data, and decode and display such incoming data.

It is quite likely that infantry soldiers of the future will resist wearing one or several optical devices between their eyes and the world around them: spectacles or telescopes, thermal imaging sights, light intensification viewers, laser and ballistic protective systems.[54] Some or all of these could be incorporated into the protective helmet, along with reliable communications to insure that the wearer is seldom, if ever, isolated from his companions. With a powerful computer in the helmet, it would even be possible to incorporate a modest language translation capability to facilitate a soldier's interactions with allies, the people in controlled foreign territory, or prisoners of war. DARPA has recently advertised for small businesses to conduct exploratory development of a low cost "integrated earphone, night vision goggles, and burst communications in helmet for low probability of detection and intercept for small units."[55] Computer-generated icons could readily be projected into such a helmet's display.

Much objection to "smart helmets," to enriched personal communication on the battlefield, to helmet mounted displays, or to a "Cray for each soldier's field-jacket pocket," as some have described the personal computer, turns on the mistaken notion of information overload: the soldier, it is held, would be over-equipped, too busy either to interpret the flood of audio and visual cues he would receive, or to provide meaningful responses. But the communications proposed here would be mainly autonomic, and would require no act of volition by any soldier beyond summoning "display friendlies." Imagine a soldier, his hands fully occupied, speaking that command: his throat microphone would interact with the speech recognition sub-system in his processor to toggle the directed

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54 "Protective Eyewear," *Army*, op. cit. The Army has purchased 100,000 ballistic/laser protective spectacles (B/LPS). The Army Medical Research Acquisition Activity at Fort Detrick, Maryland, will shortly publish a Request for Proposals "to develop ocular protection against laser radiation required by military aviators and ground personnel," *Aerospace Daily*, February 27, 1990, p. 360.

55 SBIR, DARPA 90-0555, 1989, p. 403. Cf., "Purchase Description, Helmet-Mounted Infantry Display (HELMID)," U.S. Army Communications-Electronic Command, Night Vision and Electro-Optics Center, Fort Belvoir, Virginia, 11 February 1986, DAA 807-86-R-8059.

display into his field of view. His computer would summon from the network the location of any friendlies or friendly mines in his field of view, and show their locations as an overlay on his panorama. Satisfied that the field was clear, he could then command "weapon: fire," pull the trigger himself, or move ahead confident that he knew where the hazards from friends were located.

E. IMPROVING THE MEDICAL SYSTEM

From all reports, medical service during JUST CAUSE was exemplary, and few improvements could have been made with current technology. But the Panama experience proved again that time is the essence of responsive medical support; fatalities were held down, and the seriousness of wounds and injuries abated because helicopters were plentiful, communications sound, superb medical facilities close at hand, and swift evacuation to CONUS hospitals the norm. In fact, if there were flaws in the system, they stemmed from the very rapidity of the evacuation chain, that sometimes made it difficult to record injections, incisions, or other medical procedures, and to insure that one station knew what other stations had done to the patient.

In a less favorable circumstance, it would seem prudent to exploit the involuntary, computer arbitrated, communications network described above to plug each soldier directly into the medical system. ST's life support system could include vital sign monitors that would remain off the network unless either (1) they were interrogated by the unit, or (2) they detected an aberration signifying that soldier had been wounded or injured. In the latter emergency, the soldier's personal communication set would autonomously broadcast both his location and his symptoms, permitting triage to begin immediately, even before he could be brought to an aid station or field collecting element. Moreover, pneumatic tourniquets could be commanded into action, and drugs injected through an iontophoretic delivery system built into the battle dress.[56]

That capability would address three areas of need as expressed recently by the Surgeon General's Center of Excellence.[57] The first is as follows:

> Based on the concept of the totally encapsulated soldier, a fundamental part of the protection system is to monitor the vital signs of the soldier. As a soldier would enter hostile environments, certain indicators would sense the well-being of the individual. Monitoring of the data from a soldier force

[56] Moore, op.cit., p. 10. Cf., "The Phoresor II," Center for Engineering Design, University of Utah.

[57] COE, DASG & WRAMC, 16 January 1990.

would allow the unit commander to assess the physical and emotional readiness of the force, and indicate areas of problem.

The Center of Excellence (COE) will undertake a systematic comprehensive study of vital-sign physiologic parameters which would be critical to the inclusion in the Super-Troops' Physiological Monitor System (STPMS). An expert study group of U.S. Army Medical Corps physicians will develop the necessary listing of vital monitoring parameters which need to be addressed in the design of the ST unit. Further, detailed technical specifications of the monitoring devices will be proposed so as to set physiologic standards of resolution, sensitivity, and range parameters for the sensing devices.

The focus of the medical design and evaluation will encompass extra- and intra-body environments.

The extra-body environment will be that space between the exoskeletal encapsulation and the integument of the body....Two types of intra-body monitoring which will encompass major organ system function will be investigated. They are (1) noninvasive and (2) invasive monitoring.

In noninvasive intra-body monitoring, probes that may be ingested will be evaluated to indicate their temporal effectiveness in certain monitoring functions. Obvious parameters as heart rhythm and rate, respiration rate, blood pressure, intra-body temperature will be factors proposed and evaluated.

In the invasive monitoring investigation, transdermal implantation and other potential methods will be evaluated.

The second is a straight-forward extension of the friendly-locating system described above, a system that the medics believe would add significantly to soldier confidence and morale:

The geographical location of combat casualties in a combat zone is crucial information for the initial treatment of casualties....The Medical Combat Casualty Locater System (MCCLS) would pinpoint the location of a downed soldier. In addition to buddy-aid available, combat medics and medical personnel would be able to locate and retrieve casualties in a fashion more rapid than traditional modes of response. The response of the Medical Corps, with greater knowledge at hand, would increase the probability of saving lives.

Individual soldiers, regardless of function, would be equipped with the necessary developed MCCLS instrumentation. The MCCLS would be able, like the public medic-alert communication system, to indicate where they were in trouble.

The third is a rapid means of building the medical record of a combat casualty and insuring that a complete record accompanies the patient as he is moved within the

evacuation system. What is proposed is a set of compact input-output devices for medics that could interact with the chip or chips embedded within the soldier's dogtag. Any medical intervention could then easily be entered as a permanent record, that record could be immediately available to any medic contemplating further treatment, and the record could be assured of accompanying the patient wherever he goes.

Development of these medical subsystems could proceed hand-in-glove with that of ST. Early validation could be accomplished via I-Port in engagement simulations.

IX. ASSESSING COMBAT EFFECTIVENESS

One cannot evaluate JUST CAUSE for "what might have been." It was a success, and a striking success at that. The point of the foregoing discussion is that participants in future such operations should have at their disposal the very best that American inventors and engineers can devise. ST and I-Port seem within reach. If a SuperTroop-like battledress could be fielded, the benefits cited in Figure IX-1 might materialize for future dismounted operations.

Better operational execution

- Higher assurance mission (less vulnerable assault echelon)
- Swifter performance (well coordinated fire and movement)
- Advantageous tactical agility (better C^3I)

Lower operational costs

- Fewer casualties
- Lower mortality among casualties
- Speedier recovery among wounded, earlier return to duty

Facilitated Combat Development

- Weapon system integration easier
- Force structure lightened: fewer foot fighters at risk
- Robotic interfaces simpler

Improved Training Development

- Evaluation easier: dense data on every soldier all the time
- Feedback simplified: voice and graphics available
- Safer: biologic monitoring continuous

Figure IX-1. Possible Benefits from SuperTroop

There will be, almost certainly, drawbacks as well--e.g., in logistics and counterintelligence. But to anticipate how to take advantage of the potential *plus* of ST, as well as how to engineer out as much potential *minus* as possible, would be among the primary purposes of I-Port. I-Port will enable virtual battles within Advanced Distributed Simulation and detailed analyses of the performance of ST-equipped fighters therein.

X. OPERATION JUST CAUSE--A CASE FOR I-PORT?

The U.S. forces employed in JUST CAUSE included units stationed in or pre-deployed to Panama, plus units from:

U.S. Army	U.S. Air Force
Fort Bragg, N.C.	Military Airlift Command transports from 21 wings
Fort Ord, Cal.	Strategic Air Command tankers from 26 squadrons
Fort Polk, La.	Gunships, from Eglin AFB, Fla.
Fort Lewis, Wash.	

These, together with small units from the U.S. Marine Corps and the U.S. Navy, acted under the operational command of Joint Task Force South, the headquarters of which was formed around that of Lt. General Carl Stiner's XVIIIth Airborne Corps.

General Stiner faced one of the most daunting tasks ever assigned an American general. No commander had ever been asked in a time of nominal peace to concentrate, over great distances, so many troops and aircraft on so many dispersed objectives, from disparate units stationed across the United States. Further, Stiner had to prepare his forces without providing warning to a demonstrably evasive quarry.

What the force lacked was a means for rehearsing each of the 27 separate night assaults--each a multi-Service operation--without alarming the numerous communities from which the executing troop units were to be drawn, or tipping off the Panamanians. While troop units could conduct exercises resembling their role in the operation in local training areas, the synchronization of the overall operation must have been among foremost concerns and key leaders were no doubt constrained from assembling and conducting holistic rehearsals including: inserting special operations forces; assuring precise, discriminate preparatory and supporting fires; timing troop aircraft formations so that flight leaders could navigate the entire route, form for drop, and practice drop-point primaries and alternates, and so that jump masters could interact with flight crews the while. Preferably, these operations would have flowed into those of troop units assembling after drop, moving per mission on the ground, and concerting fire and maneuver at their several

objectives. Preferably, too, rehearsals would have been realistically two-sided, and "replayed" at will to explore "what-if" excursions, or to accommodate revised plans. No "war game" or "battle simulation" would suffice: air crews, jumpmasters, and soldiers fighting afoot need rich audio-visual stimuli if they are to understand what is expected of them, and to anticipate a wily enemy. What the force needed was Advanced Distributed Simulation Technology to meet the following requirements:

- Ability rapidly to generate digital terrain data bases with current works-of-man and up-to-the-minute portrayals of defenses.
- Secure, distributed engagement simulation that supports 10^3 participants.
- Capability to accommodate differences in granularity of imagery ranging from jet pilots to riflemen.
- Individual portals into the simulation for commanders, leaders, and fighters on the ground.

The current land warfare SIMulator NETwork (SIMNET) is built around mockups of a particular type of vehicle--an armored fighting vehicle or an aircraft. The battle environment--terrain, friendly forces, enemies--is portrayed to the vehicle crew through visual and audio inputs, these derived from a digitized terrain data base and interactions with an object-oriented digital model that tracks and reports on other mock-up/crew combinations, representing both friend and foe. To provide the force that the requirements describe, a mechanism to rehearse plans for a large contingency force, significant new technology would have to be developed; fortunately, much of it is adumbrated in the SIMNET program to date.

A. TERRAIN DATA BASE GENERATION

So long as the primary thrust of SIMNET [soon to become Close Combat Tactical Trainer (CCTT)] was preparing heavy forces for close combat in Europe, relatively little emphasis was placed on quick preparation of terrain/cultural detail for the digital "battlefield." It was assumed, probably correctly, that sooner or later the Defense Mapping Agency would make available digital models of terrain in sufficient extent and detail to warrant confidence that users of CCTT could conduct their battle wherever they chose, so long as their choice was somewhere in the Federal Republic of Germany. But JUST CAUSE underscores the fact that battle in Germany is less probable than elsewhere, and that the priorities and schedules of the DMA could not be expected to keep pace with

politico-military developments that might prompt the next projection of U.S. force into the Third World.

What are needed, therefore, are techniques for rapidly generating a three-dimensional digital map of any objective area using a variety of inputs: such DMA digital maps as may exist, digitally-scanned paper maps, aerial photographs, satellite imagery, and even photographs and blueprints. Techniques should be fashioned for exploiting any source for the purpose of arraying enough of the physical context of a contemplated operation to facilitate the planning and mental conditioning of operational participants.

B. SECURE DISTRIBUTED SIMULATION

SIMNET is not now secure, and there are no plans to make CCTT secure. Both require fixed-site facilities, necessarily so to support the vehicular simulators, themselves bulky and not field-worthy. Moreover, SIMNET/CCTT sites will be mainly located in the wrong places for forces preparing for worldwide contingency operations. What the force requires for operational rehearsals and pre-assault training is a set of mobile simulation equipment that can be flown in when needed, to operate in any installation anywhere, networked with secure links to similar equipment anywhere in the world. Participants in the simulation could enter its virtual battlefield through an ST helmet, or through I-Port equipment.

C. GRANULARITY OF IMAGERY

Not all participants will have the same requirements for detail. A troop transport pilot might need only coarse details of land masses over which he would fly enroute to the objective area, but he and an airborne tanker pilot might require a fairly detailed depiction of each other's aircraft to rehearse an in-flight refueling. Again, the troop transport pilot, crew chiefs, and troop jumpmasters would need amplified detail of ground features as they approach drop point. By and large, SIMNET Computer Imagery Generators (CIG) are good enough now to support these evolutions, albeit simulators and computer models for the USAF aircraft have not been built.

More extensive detail would come into play for participants on the ground, and here a significant new development, I-Port, the Individual Portal into the virtual battle, would be a *sine qua non*. Each individual soldier has a role in an airborne assault, and therefore the simulation should be based on the individual--friendly and enemy--who should be portrayed in its iconography. The amount of detail required of the terrain/culture data base

would be a function of the tactical play: where detail exerts an influence on the battle, it should be apparent to participants. If the objective involved intricate tactical teamwork, as in freeing hostages, the digital model of the objective might be realistic down to showing windows, doors, furniture, and other potential obstacles, cover, or concealment. Figure X-1 depicts these progressively more granular graphical requirements.

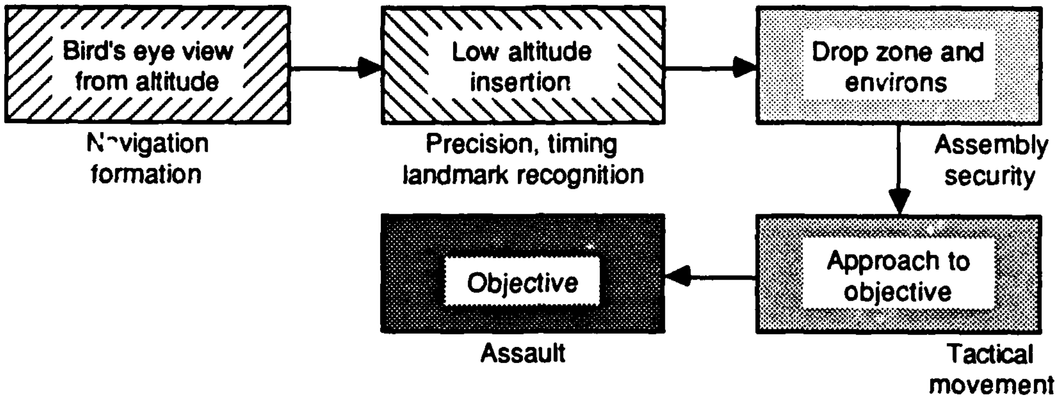

Figure X-1. Progressive Granularity in Graphics

The CIG technology currently used in SIMNET provides granularity as a function, *inter alia*, of (1) the field of view required to be displayed (range and angular width), and (2) the numbers of graphic displays (channels) that must be supported by each CIG. The greater either (1) or (2), the less detail. But note that individuals fighting on foot have much lower range requirements than crews of vehicles or aircraft, and, while a tank simulator requires 8 channels, each ST/I-Port CIG would be addressing a single helmet-mounted display, with one or two channels.[59]

The RAND Corporation has conducted an analysis of the compatibility of a high definition display with SIMNET's more coarse depictions, and concluded that each has its utility, and with appropriate interfaces, could be made interactive within the same virtual battle.[60] The high definition virtual reality viewer that was the subject of that study is that used in the the U.S. Army/NASA Ames Research Center's Crew Station Research and Development Facility (CSRDF), a helmet mounted display manufactured by CAE

59 Bess, R.D., "Tradeoffs in the Configuration of Computer Image Generation Systems," BBN Systems and Technologies Corporation, Bellevue, Washington, 1988.

60 RAND Corporation, "Feasibility of Applying SIMNET technology to the Weapon Systems Development and Acquisition Process," briefing for DARPA, November, 1989.

Electronics Ltd., of Quebec, Canada.[61] Also relevant is research by the USAF Air Systems Command with "virtual cockpits," and its proposed extension in Advanced Distributed Simulation Technology.[62]

D. INDIVIDUAL PORTALS INTO SIMULATED BATTLE

Thus far this paper has referred to two related but distinctly different technological developments: (1) I-Port, a means for taking an individual combatant into a virtual, SIMNET-like battle, and (2) the "Command Post in a Helmet," a means for taking information to an individual leader to aid his decision-making. Both developments propose computer-generated graphics upon close-to-the-eye display(s); both would require significant on-person computing power; both would share the same technological "gene pool." But I-Port would be a training system and, as such, could be built to commercial standards without much regard for field-worthiness or ruggedness (beyond common-sense soldier-proofing) or threat of hostile counter-measures; I-Port would have to communicate within the distributed simulation, but not otherwise. I-Port might figure in operations as a rehearsal means, but it it unlikely to be used in combat. The Helmet CP, however, ought to evolve from a specific form of I-Port--Commander's I-Port--into an apparatus that could free leaders and staff personnel from the necessity for collocation on the battlefield. A command post would be wherever the commander chose to be, his Helmet CP instantly providing him virtual access, via distributed communications functioning not unlike those of SIMNET, to all his staff and to whatever graphic and aural information they could provide to assist his decisions. The information-providers themselves could be distributed, and whole new architectures for C^3I, more economical in people and equipment, less vulnerable, and more efficient than today's hierarchies, could become possible.

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61 CAE, Ltd., describes their device as a "Fiber-Optic Helmet Mounted Display--Visual system presents a panoramic, high-brightness, high-resolution, stereoscopic image of unparalleled detail and clarity." Interestingly, the CSRDF cockpit is not mounted on a motion simulator, and is largely "virtual," that is, aside from a few levers and his seat, what the pilot senses of his surroundings inside or outside his aircraft is entirely computer generated.

62 The USAF Human Resources Laboratory (HRL) ACME (Aircrew Combat Mission Enhancement) Network will conduct R&D "to accommodate the training requirements of multiple distributed fixed wing fighters and close support aircraft, and their appropriate command and control elements....This task will require the incorporation of numerous simulators with various levels of fidelity...," ADST Solicitation, MDA972-90-R-0001, January 29, 1990, Attachment 1, p. 7. ACME will seek to internet with appropriate communications and computers full field-of-view dome simulator(s), helmet mounted display(s), air intercept trainers, reconfigurable (virtual) cockpit(s), and plan view display(s).

What the JUST CAUSE force required for mission rehearsal is I-Port. Enriched mission rehearsal has been pursued by the armed forces, especially the Special Operations Forces, for many years. Various forms of "vicarious travel" have been devised. For example, using computer-managed video-disk machines, it has been possible to explore a small town, traveling through it at will, observing high-quality photographic images. The technique depends on being able to take and store tens of thousands of individual photographs, which are presented to the viewer in the sequence he would encounter each view on his chosen route, at whatever speed he chose to "travel."[63] Usually, the display is a work-station-sized screen. More recently, techniques have been devised for enhancing digital map data with recent overhead photography--preferably stereo pairs--to create a three-dimensional digital model; this model drives a CIG, and the viewer can be presented a near-photographic quality panorama from any particular point of view.[64] The graphic display typically portrays a vehicular perspective, such as that through a pilot's canopy in an aircraft, as it does in SIMNET, but it can also be presented at a work-station, or projected onto a large screen for large groups.

The U.S. Air Force has a training development under contract, the Special Operations Aircrew Training System, said to be the largest of its kind. The respondents will eventually provide the Air Force criterion referencing for over 10,000 tasks, and design some 268 courses to teach these. These, of course, are designed to train crew members up for mission proficiency, but they do not address specific operations. However, 10-20 percent of the contractor's effort is to be devoted to building a mission rehearsal system capable of being tailored within a few hours to any actual combat operation. The rehearsal must have sufficient verisimilitude to enable crew members to practice intra-crew coordination, to refine tactics and techniques, to improve their situation awareness, and to enhance their decision-making capability. Various versions of the system are under consideration, but all include one or more high-fidelity flight simulators, and various adjunct displays. Typically, these would be collocated in a facility, or center, in which mission participants and supervisors would meet to prepare for their operation.

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63 E.g., the "Aspen Movie Map" project, 1979-1982, described in NASA-Ames, Florida: 239-3 (a DARPA Project).

64 Cf., Project 2851, "Rapidly Reconfigurable Data Base," prepared by General Electric Aerospace, which portrays terrain and structures in the vicinity of Nellis Air Force Base, Nevada, and has been demonstrated with a GE CompuScene CIG for mission rehearsal of USAF SOF aircraft.

The United States Special Operations Command has launched a comparable development with its Special Operations Forces Planning and Rehearsal System (SOFPARS), which would provide for mission rehearsal not only for air crews, but also land and sea forces. Exploratory development has been accomplished by the Argonne National Laboratory, and a Request for Proposal for further development is expected in FY 1991. The parameters of SOFPARS are as yet undefined, but it too appears to involve high-fidelity vehicular simulators in a central facility.

The experience of the National Aeronautics and Space Administration with mission rehearsal is germane.[65] The Johnson Space Center starts with construction of a rudimentary simulator; training development is driven by experience with the simulation: tasks are defined, conditions described, and standards set based on experience within the simulation. As the training development proceeds, the simulator evolves, becoming more sophisticated, until, ultimately, means are on hand to rehearse astronauts for an actual mission. Moreover, Ames Research Center has aimed at building means for training astronauts in space, providing them in a computer-controlled, "multi-sensory virtual environment" with which they can "viscerally interact."[66] The Ames experiments and force-feedback research at the Jet Propulsion Laboratory have contributed to the Flight Telerobotic Servicer (FTS), a 6-foot tall anthropoid mechanism in development at Goddard Space Center; an FTS is scheduled to be tested in space in September 1991.[67] Two lessons for the Department of Defense seem evident in the NASA experience: (1) develop simulation first; (2) simulators can evolve into operational systems.

I-Port, a simulator for projecting individuals into a virtual battle, can function as a mission rehearsal device. It need be neither expensive, nor ponderous. It could readily be rendered secure from electronic intelligence collection. Moreover, since its central purpose is to access a distributed simulation, I-Port could be provided to an operational participant wherever he may be, even enroute to the objective area. And I-Port could evolve into the Helmet CP.

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65 Holkan, Robert K., presentation on programs at the Johnson Space Center, TRADOC Training Technology Workshop, USACGSC, Fort Leavenworth, Kansas, March 23-24 1989.

66 Fisher, op.cit.

67 Freiherr, G., "Invasion of the Spacebots," *Air & Space*, February/March 1990, pp. 73-81. Martin Marietta is the principal contractor for FTS.

XI. A DEVELOPMENT PLAN

The concept proposed for developing SuperTroop is to begin with I-Port, and to use I-Port to define both the requirements for ST and the technological responses to those requirements.[68]

- I-Port
  - Powerful, compact, light personal computer
  - CIG and close-to-the-eye display
  - Prototype exoskeleton for full-body interaction
- Exoskeleton
  - Structural members and actuators
  - Power
  - Computer-monitored strength enhancement and stabilization
- Armor
  - Improved cranial/thoracic shields
  - Full body protection
  - CBRNT countermeasures
  - Defenses against Directed Energy Weapons
- Biologic Support Systems
  - Life support
  - Monitors for vital signs
  - Personal interface with field medical service
- C^3I
  - Sensors, including robotic sensors
  - Displays and control measures
  - Low probability of intercept communications
  - Intra-unit packet protocols for polling, positioning, and prompting
- Lowered Observables
  - Active counter-detection measures
  - Camouflage and other passive counter-detection measures
- Weapons
  - Self-protection
  - Means for contributing to unit mission
- Power
  - Robust, enduring, on-person power supply
  - Logistic sustainability

Figure XI. SuperTroop Technology Initiatives

68 This proposal was developed after consultations with DARPA Program Managers, and with Dr. Robert Jacobs of Illusions Engineering, Inc., one of the architects of SIMNET.

While the foregoing is an ambitious, even daunting list, there is in fact a significant body of enabling research that supports approaches to each undertaking (Fig. XI-2).

Collective distributed simulation programs:
- SIMNET/CATTS
- USAF ACME
- ADST/ABS/BFIT

Exoskeletal system studies
- PITMAN (LANL)
- Battelle Study for JSSAP
- DARPA's Robotic Manipulators and Legged Locomotion
- USA/GE exoskeleton project
- U. Utah telerobotics, prostheses, and MEMS research

Virtual reality research
- NASA Ames virtual environment display/ interface workstation
- NASA/USA CSRDF
- USAF ASC virtual cockpit experiments
- SRI digital models of human anatomy
- UNC molecular manipulation models

Power systems
- LANL/Sandia/Argonne Laboratory energy-cell experiments

Armor, DEW defenses
- DARPA TTO programs on armor, anti-armor, mines/CM
- DARPA DEW programs

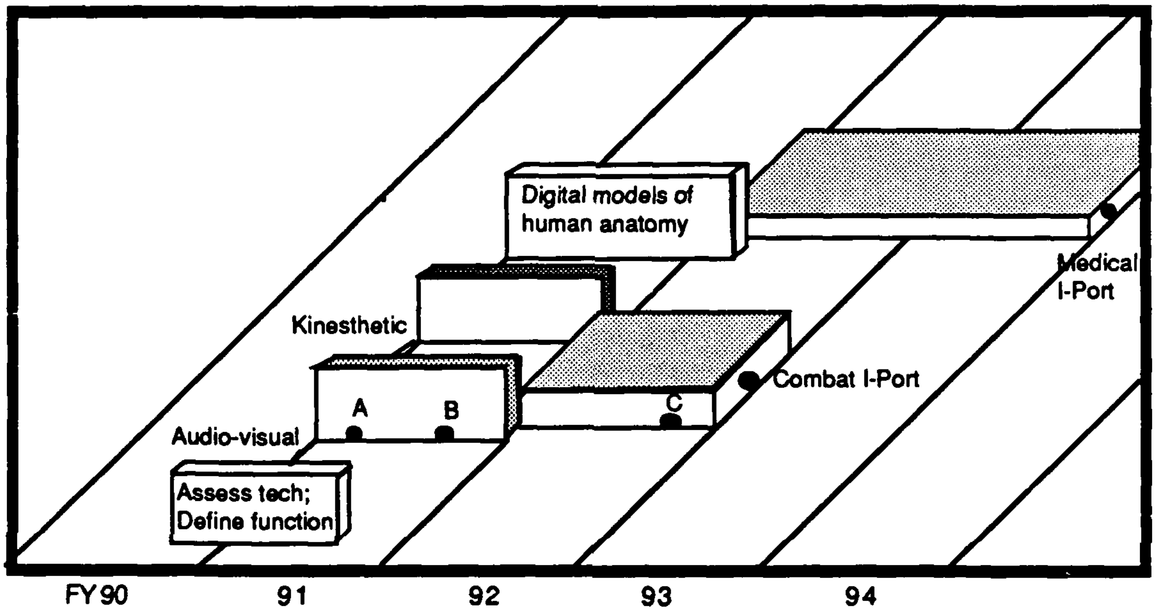
C^3I
- Service communications programs
- DARPA geopositioning programs
- NASA experiments with telepresence and close-to-the eye displays

Figure XI-2. Enabling Research for SuperTroop

A. DEVELOPING I-PORT

With what has been learned about military applications of "virtual reality" in the DARPA-Army SIMNET demonstration, now concluded, and about robotic technology, man-machine interfaces, personal computers, and communications in other recent DARPA projects, it appears possible to build I-Port now. Two developments for input-output devices should be pursued simultaneously: (1) audio-visual systems built into a cranial encapsulation; and (2) kinesthetic/tactile systems in the form of a computer-mastered exoskeleton. With support from the Services, the audiovisual development, as it progressed toward I-Port, could produce ADST "spin-offs," each of which would significantly enhance prospects for "seamless simulation"--the ability, called for in ADST, to mix and match various forms of simulated battle without detracting from the training value for any participant.

A third development is also possible--a medical version of I-Port. In this case, there is no digital data base to establish common references comparable to the digitized terrain or other spatial environments that serve existing simulations. Hence, existing digital models of human anatomy would have to be collected into a comprehensive digital, three-dimensional "map" of the human body. With such a data base it appears possible to meld the I-Port development into an adaptation for medical service personnel (Fig. XI-3).



Products marked ●

A--CCTT Binocular
B--CCTT Wpn Sight
C--Hybrid Optical-CIG Binocular

Combat I-Port
Medical I-Port

Figure XI-3. A Project Plan for I-Port

The "products" labeled A, B, and C in Figure XI-3 are these:

Product A is a visual system in the form of a military binocular for viewing the battlefield of the Close Combat Tactical Trainer, or any compatible simulation. This close-to-the-eye viewing device will make possible active roles in the simulation for individual scouts in observation posts, forward observers for artillery and mortar, and other individuals not mounted in a combat vehicle.

Product B is an adaptation of this same system, in the form of a weapon sight for non-vehicular weapons, such as shoulder-fired air defense missiles or dismounted anti-tank

systems. The visual display could replicate thermal or light intensification imagery, when appropriate.

Product C is a hybrid system, a binocular within the optical train of which computer-generated iconography could be inserted, designed to provide decisional stimuli in exercises with actual equipment in the field by supplementing the portrayal of both opposing and friendly forces.

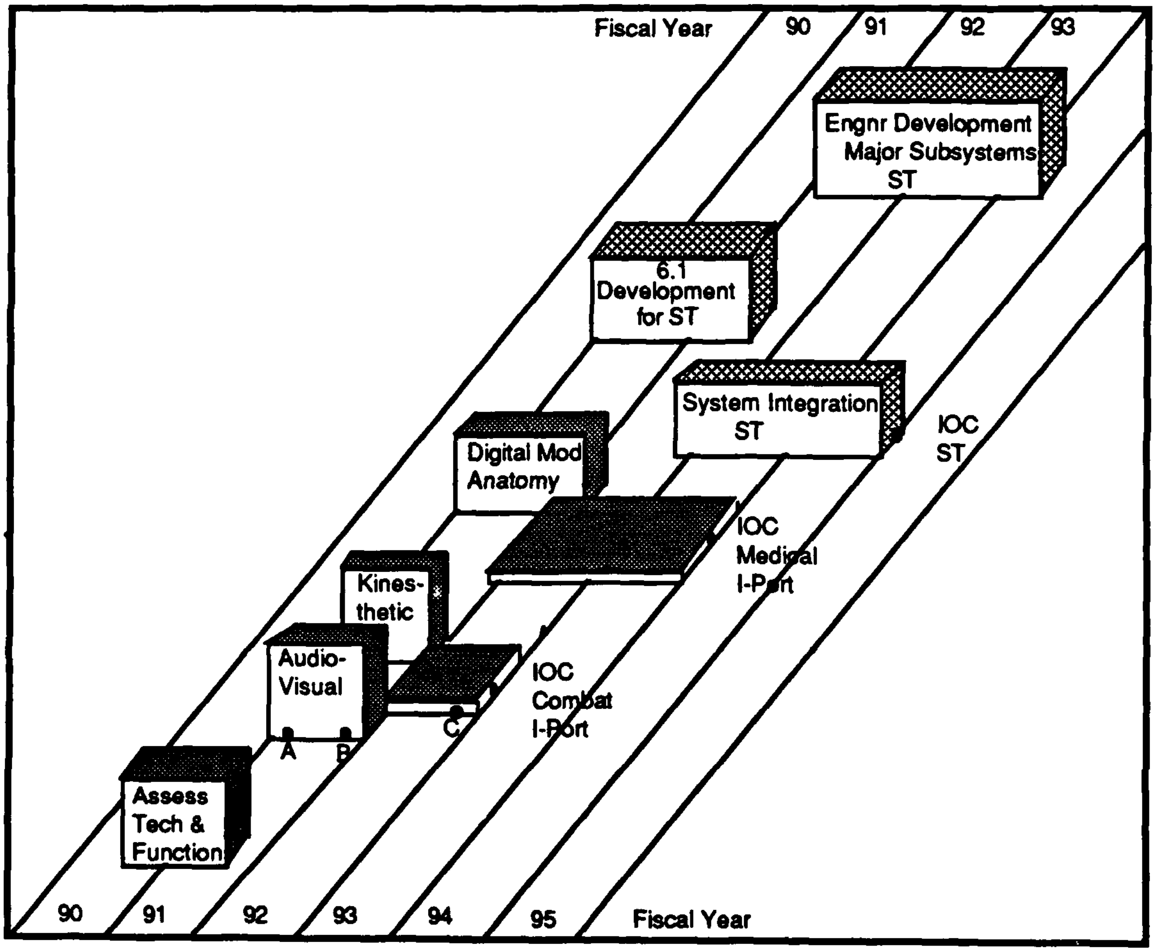
All three products would embody technologies central to both the combat and the medical versions of I-Port, and eventually to SuperTroop as well.

B. PROCEEDING TOWARD SUPERTROOP

An overall development scheme for SuperTroop is shown in Figure XI-4.

Concurrent with I-Port efforts, it would be desirable to initiate exploration of basic technologies--in DoD terms, 6.1-6.2 research--to meet those challenges of SuperTroop not addressed in the I-Port development. Engineering development would follow, and ultimately system integration. This plan proposes unprecedented cross-fertilization between training developments and materiel developments. Given the need for extensive coordination among DARPA, the Army's Training and Doctrine Command and its Materiel Command, and one or more of the National Laboratories, the program should center on the Advanced Simulation Development Facility of IDA, where the first functional I-Port will be available to examine ST concepts, and to experiment with ST components as they are prototyped. This program could produce technologies widely applicable throughout the armed services--and in civilian life as well. A number of these are listed in Figure XI-5.

Initial estimates of program costs are $70 million over 5 years.



Products marked ● :

A-- CCTT Binocular
B-- CCTT Weapon Sight
C-- Hybrid Optical-CIG Binocular for NTC,CMTC,JRTC,FTX

Combat I-Port
Medical I-Port

Figure XI-4. A 5-Year Plan for SuperTroop

Information Technologies
• Team/unit consciousness mechanisms and techniques • Micro electric mechanical systems (MEMS) • Comfortable, efficient man-worn displays • Precision manipulation of virtual objects • Man-worn, sense-amplifying sensors • Very small, personal computers for data processing and image generation • Synthetic environment for individuals, changeable in real time • LPI personal communications • Unit polling and monitoring protocols • Graphic personal decision aids • Master-slave controls for small robots • Robotic scout/weapon designator • Digital models of anatomy and anatomical displays • Embedded geopositioning • Myoelectric sensors and controls • Vitality monitors • Novel tactile and kinesthetic techniques • Engagement simulation for individual training and mission rehearsal
Tactical Technologies
• Exoskeletal strength inducer, mobility aid • Orthopedic bracing for parachutists • Personal micro-climactic conditioning • New weapon system concepts • Adaptive camouflage/ personal signature reductions • Mine record and dissemination • Enhanced fire-maneuver coordination • Automated casualty location/remote triage/first aid • Man/robot infantry teams • Whole-body armor protection against blast, KE, and thermal threats • Protection against Directed Energy Weapons: e.g., lasers, microwaves
Materiel Sciences
• Lightweight, anatomically conformal rigid armor or fabric • Lightweight structural members for exoskeleton • Personal power source • Background adaptive, chameleon camouflage materials

Figure XI-5. Spin-off Technologies from SuperTroop

C. A DECISIVE TECHNOLOGICAL INTERVENTION FOR INFANTRY

SuperTroop *via* I-Port could dramatically upgrade the combat effectiveness of the American foot soldier through the following capabilities:

- Amplify his senses and his physical strength
- Aid with a computer his ability to move, shoot, and communicate
- Strengthen his awareness of unit
- Decrease his personal vulnerability to weaponry
- Equip him to control robots or to fight through telepresence
- Train him experientially against thinking opponents.